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RESIN TRANSFER MOLDING OF TEXTILE COMPOSITES

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FOREWORD

This report describes work accomplished under "Resin Transfer Molding of Textile Composites" Contract NAS1-19247 Task 5 and Task 7 subtasks 7.1 and 7.2. Sponsorship for this program was provided by National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia. Task 5 was initiated in June 1991 and Tasks 7.1 and 7.2 were initiated in November 1991. These tasks were completed in March 1993.

Mr. Clarence C. Poe Jr., NASA Langley Research Center, was the NASA Task Technical Monitor. The Materials & Processes Technology organization of the Boeing Defense & Space Group was responsible for completing these tasks. The following Boeing personnel provided critical support throughout the program:

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ABSTRACT

The objective of this program was to provide resin transfer molded (RTM) textile composite panels, tubes, and angle sections to the NASA Mechanics of Textile Composites Working Group for testing and evaluation. The textile preform designs and requirements were established by NASA in collaboration with Boeing and several vendors of textile reinforcements. Four categories of preform architectures were investigated in this program: stitched uniweave, 2D-braided, 3D-braided, and interlock woven. Hercules AS4 carbon fiber was used in the braiding or weaving of all preforms.

Interlock woven fabric is a three dimensional fabric in which yarns are woven through the thickness to provide greater resistance to delamination than conventional laminates. The interlock tows wrap around the weft or fill yarns which are perpendicular to the warp yarns and in the same plane. 2D braid architectures were selected to test specimens produced by varying three parameters: the filament count of braider yarns, the percentage of fixed (axial) yarns, and the braid angle. The parameters varied in the stitched uniweave preforms were: thread type (Kevlar or S-2 glass), stitch row spacing, number of stitches per inch, and fiber tow size. Samples of two 3D braided preforms were supplied by Quadrax at no charge to the program and then molded using funds provided by Boeing.

The Shell RSL-1895 epoxy resin with Shell Epon Curing Agent W was selected for producing all panels. The 1895/W system, developed for RTM, has comparable properties to the 3501-6 epoxy resin, and has improved hot/wet properties and a higher neat resin modulus than some other epoxy matrix resins. The 1895 resin has a combination of difunctional and multifunctional epoxy resins. The curing agent W is an aromatic amine curing agent, and does not contain methylene dianiline (MDA).

Our process of resin transfer molding uses a series of parallel plates with a picture frame style mold that forms the cavity. The mold is placed inside a heated-platen press for heating and clamping. Each resin component is heated separately to the injection temperature. The two components are then mixed together moments before injection into a runner system that feeds four ports located at the center of each side of the picture frame. Resin infiltrates the perimeter of the preform and is vented at the geometric center or center line. The method of injecting resin from the perimeter was highly successful because it completely eliminates resin blow-by. With perimeter injection, the preform's length and width tolerances are not important because the preform does not need to fit snugly into the mold cavity. All flat panels were processed in the picture frame mold. Although a special tool was needed to fabricate the curved panels, the same injection and venting concept proved successful.

During the early stages of this program, microcracking was observed in some of the photomicrographs of the interlock woven architectures. Microcracking occurred predominantly in the interlock woven architectures. And, of the six interlock woven architectures, microcracking occurs most often in the orthogonal interlock materials. Microcracking is caused by the chemical shrinkage of the polymerization process, the fiber/matrix thermal contraction mismatch during cool down, and the restraints to resin shrinkage applied by the architecture during the cure process. We were able to reduce the amount of microcracking by using a lower-temperature (250°F), extended-time cure cycle. The microcracking in the orthogonal interlock panels could not be eliminated, given our current set of materials. The extended cure cycle was used in the fabrication of all subsequent interlock woven and stitched uniweave panels (including the 3D braided-Quadrax panels). It was not necessary to use the extended cure cycle in the 2D braided architectures because microcracking was not prevalent in these panels.

In order to use textile composites in primary structures, a means of non-destructive inspection (NDI) is necessary for both fabrication inspection and in-service damage. The use of textile composites in aircraft structure is not mature enough to bring visibility to NDI technical issues. Current usage of textile composites is in secondary structure where strength is not a design driver. To get an understanding for the state-of-the-art in

nondestructive examination of textile composites an industry survey along with a literature review were initiated. The survey results showed that the types of defects typically found in textile composites included dry areas, improper ratios of resin, contamination of the preform with mold release agent, cross-contamination of fiber type from the braider, fiber pinching, and fiber wash. The literature review resulted in a list of several hundred citations relevant to the study. Initial review of the literature focused on porosity determination in textile composites.

Ultrasonic NDI was performed on all parts produced in Task 5 and 7 after completion of the RTM process. This was done to: (1) determine the quality of molded panels, tubes, and angle sections, (2) provide feedback during the RTM process development that occurred in the early stages of the program, and (3) determine the ability of ultrasonic NDI techniques to detect defects in RTM parts made from textile preforms. Ultrasonic scanning is a highly automated process and proved to be an easy and cost effective way to NDI molded textile composites. The scanning allowed us to eliminate areas of high attenuation from inclusion into mechanical test program. Although there was no acceptance or rejection criteria established in the SOW, the ultrasonic C-scans, in combination with visual inspection, proved to be a highly effective means in judging the quality and identifying specific areas of porosity of the panels following completion of the RTM process.

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1.0 INTRODUCTION

The objective of the tasks described herein was to provide resin transfer molded (RTM) textile composite panels, tubes, and angle sections for the NASA Mechanics of Textile Composites Working Group for testing and evaluation. Much of the testing and evaluation was performed for NASA by Boeing under Contract NAS1-19247, Tasks 7.3 through 7.7. The testing objective was to develop mechanics methods to predict mechanical properties of textile composites, because textile composites differ from conventional laminated composites in several important respects. For example, the strain field in textile composites is less homogeneous than in laminated composites, and the unit cell size (smallest repeating unit) of textile composite architectures needs to be considered in mechanical test selection and test specimen design.

The textile preform designs and requirements were established by NASA in collaboration with Boeing and several vendors of textile reinforcements. Hercules AS4 carbon fiber was selected to be used in manufacturing all preforms because (1) an extensive database exists for composites produced from this yarn and (2) its low cost makes it attractive for commercial transport aircraft. The yarn is also available in three tow sizes (3K, 6K, and 12K) which is advantageous for producing balanced textile composites. Shell 1895 epoxy resin and Shell Curing Agent W were selected since this epoxy resin system met the requirements for RTM and mechanical performance. RTM requirements included low viscosity in the desired temperature range for injection and sufficiently long pot life. Mechanical property requirements included high neat resin modulus (approximately 0.4 to 0.5 Msi), reasonable toughness, and good retention of mechanical properties under hot/wet exposures.

Upon receipt of preforms and resin, process development was performed to (1) RTM multiple panels at one time, (2) RTM multiple narrow panel sections with braided edges, and (3) RTM angle panels (one at a time). All panels and parts produced at Boeing were ultrasonically scanned, and the fiber volume fractions of selected panels were determined by acid digestion.

Microcracking was observed predominantly in the interlock woven fabric. The microcracking appeared to occur because of the high residual stresses that may form in 3D architecture composites. The more orthogonal the interlocking yarns through the thickness were, the greater the tendency was for microcracking to occur. For example, more microcracking occurred in the orthogonal interlock woven fabric composites than the layer-to-layer interlock woven composites or in the angle-interlock composites. Modifications to the RTM process to minimize this tendency to microcrack were successful in reducing, but not in eliminating, microcracking.

All RTM panels and parts were ultrasonically scanned to assess their quality. Although there was no acceptance or rejection criteria for the test panels and parts, ultrasonic scanning proved to be a highly effective means of determining the quality and identifying areas of porosity.

2.0 MATERIAL SELECTION

Textile fabrics were purchased for the preforms shown in tables 2.1-1 through 2.1-5. Extra preform material was procured to provide materials for additional RTM runs or mechanical test specimens if needed.

2.1 INTERLOCK WOVEN FABRIC

Interlock woven fabric is a three-dimensional fabric in which yarns are woven through the thickness to provide greater resistance to delamination (greater toughness) than conventional laminates. For these fabrics the interlocking yarns were warp weavers, parallel to the warp or 0-deg yarns (parallel to the machine direction). The term "stuffers" also refers to the warp yarns. The interlock tows wrap around the weft or fill yarns, which are perpendicular to the warp yarns. The interlock woven fabric architectures, procured in this effort from Textile Technologies Inc. (TTI), are described in tables 2.1-1 and 2.1-2 and figure 2.1-1.

Three of the interlock woven fabric architectures arrived at Boeing partially defective. The LS-1 fabric had an architecture that deviated from the intended design because of a programming error during the loom setup. Instead of an adjacent layer-to-layer interlock, some of the yarns interlocked four layers and some interlocked no layers. Since the improperly placed yarns were located throughout the fabric, a quantity of narrower (5-in wide) LS-1 fabric was provided by TTI. However, this fabric did not have the interlock yarns in the desired pattern across approximately 0.75 inch in along one side of the fabric. Test specimens were machined from areas in these replacement panels that had the proper architecture.

The TS-2 angle interlock fabric also had minor errors in the placement of four of the interlocking yarns, which skipped over (or under) one of the weft yarns that each was intended to go under (or over). In addition to these problems, 6K tows were substituted for some of the 3K tows in the OS-2 fabric, however, this error was detected after less than half of the fabric had been produced. Although some panels were produced from defective OS-2 fabric also, the panels supplied for mechanical testing were produced from the correct architecture. The larger 6K tows could be distinguished from 3K tows in the panels by observing the tows on the panel surfaces at low magnification.

Some compaction of the through-the-thickness yarns occurred in the interlock woven panels. There was also some slight curvature to the warp yarns in the preforms and panels. The effects of these conditions on the mechanical performance of interlock woven fabric is being determined in the testing that is being performed by NASA, Rockwell, Boeing, and others in the NASA Mechanics of Textile Composites working group.

2.2 2D BRAID

2D braided preforms, 2D braided tubes, and curved panels were procured from Fiber Innovations. The tubes and curved panels were RTM'd by Fiber Innovations. Four different braid architectures were procured (described in table 2.1-3). The architectures were selected to test specimens produced by varying three 2D braid parameters: the filament count of braider yarns, the percentage of fixed (axial) yarns, and the braid angle: Small (S) and large (L) values of the three braid parameters were combined to produce four braid architectures for evaluation. The quantities of flat braided preforms (for flat panels), curved panels, and tubes that were procured are listed in tables 2.1-3 and 2.1-4.

Epoxy compatible finishes were used on all of the braid yarns (Hercules AS4 carbon fiber). A fiber volume fraction range of 50 to 60 percent was targeted for the RTM braided panels and parts. One nickel-coated AS4 carbon fiber tracer yarn was incorporated in the bias and one in the axial direction in all of the braided preforms and parts.

The flat panel braid was supplied as a stabilized fabric for resin transfer molding. The braid was slit from the mandrel, laid flat, and stitched around the perimeter of the layup. Two sections of braid measuring approximately 24-in long and 12-in wide were supplied for each flat panel. However, the narrow thin panels were braided to a net width of 1.5 in and molded to net width to study braided versus machined specimen edges.

2.3 STITCHED UNIWEAVE

Stitched uniweave preforms (table 2.1-5) were procured from Cooper Composites and RTM'd at Boeing. The preforms were nominally 24 in by 24 in. The variables to be examined in the analysis of these stitched uniweave composites were thread type (Kevlar or S-2 glass), stitch row spacing, stitching pitch (number of stitches per inch), and carbon fiber yarn tow size (3K, 6K or 12K).

Some difficulty was experienced by Cooper Composites in stitching the preforms with untwisted S-2 glass bobbin threads. Untwisted bobbin threads (through the thickness) were desired for improved Z direction performance compared to twisted threads. Small sections (approximately 6 in long) of several S-2 glass stitch rows in the S-2 glass stitched preforms were removed and replaced due to excessive fuzzing of the stitching. A total of ten stitched uniweave panels were RTM'd using the extended cure cycle.

2.4 3D BRAID

3D braid was considered for evaluation; however, the funding available did not permit the purchase of 3D braid in addition to the other architectures.

Samples of two 3D braided preforms were supplied by Quadrax at no charge to the program, and RTM'd with Boeing funding. One flat panel (measuring 11.5 in x 6.5 in x 0.11 in thick) and one curved panel were produced. A data sheet from Quadrax for the 3D braid appears in Appendix A.

2.5 KNITTED FABRIC

Knitted fabric was also considered; however, problems had been previously encountered in procuring high quality fabric. Large gaps were present in some plies and there was some yarn misalignment. When the fabric was compacted during RTM the yarns of plies adjacent to the plies with gaps would bend and nest in the gaps. These defects caused knitted fabric composites to have low compression strengths with much scatter in the data. Three panels were to be produced with stitch-knit preforms supplied by NASA. The panels were to be 12 in by 12 in by 1/4 in. However, NASA was unable to obtain stitch-knit preforms with the desired layup from the supplier that had been selected.

2.6 EPOXY RESIN

The Shell RSL-1895 epoxy resin with Shell Epon Curing Agent W was selected for producing these panels. The 1895/W system was developed to have comparable properties to the 3501-6 epoxy resin, and has improved hot/wet properties and a higher neat resin modulus than some other epoxy matrix resins. The 1895 epoxy was developed for RTM. The 1895 resin has a combination of difunctional and multifunctional epoxy resins. Curing agent W is an aromatic amine curing agent, and does not contain methylene dianiline (MDA). The 1895/W epoxy resin was selected in part because it was being used for the braided J-frames being developed on the NASA-funded Boeing Advanced Technology Composite Aircraft Structure (ATCAS) program, where composite designs for a large subsonic transport airplane fuselage are being developed.

Problems with one batch of the 1895 epoxy resin were encountered by Fiber Innovations during their resin transfer molding of the initial tubes. A poor surface finish was observed on the parts, and testing by Shell revealed that the mechanical performance of this resin was slightly lower than previous batches. The problem was traced to one resin component that had been procured from a different supplier. Shell promptly produced replacement batches of resin using better quality material for this ingredient. The tubes that were molded with the suspect resin were scrapped and replaced with tubes molded from the replacement resin batches. None of the defective 1895 resin was used in parts for this program.

Table 2.1-1. Interlock Woven Panels RTM'd at Boeing

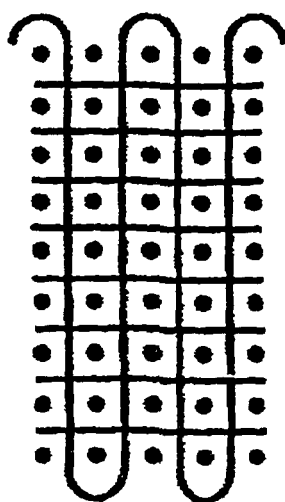
Weave code	Weave type	Warp tows	Weft tows	Weaver tows	Preforms RTM'd at Boeing	
					Flat	Angle
OS-1	Through-the-thickness orthogonal interlock	24K	12K	6K	10	1
OS-2	Through-the-thickness orthogonal interlock	12K	6K	3K	6	1
TS-1	Through-the-thickness angle interlock	24K	12K	6K	9	1
TS-2	Through-the-thickness angle interlock	12K	6K	3K	8	1
LS-1	Layer-to-layer interlock	24K	12K	6K	24	1
LS-2	Layer-to-layer interlock	12K	6K	3K	8	1
		Totals			65	6

- Notes: 1) Flat panels were 1/4-in thick x 12 in x 24 in.
 2) Angle panels were 1/4-in thick L-shaped, 3 in x 3 in x 12-in long with 0.20 in radius.
 3) LS-1 quantities included 14 - 1/4-in thick x 5 in x 24-in flat panels.

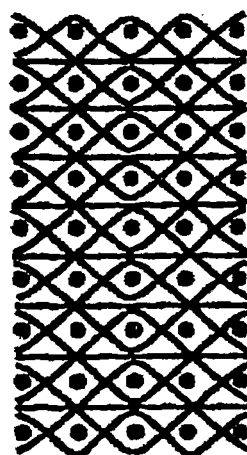
Table 2.1-2. Percentage of Warp, Weft, and Warp Weaver Yarns in the Interlock Woven Fabrics*

Yarn	Percentage in interlock woven fabric
Warp	55 to 60 percent
Weft	30 to 40 percent
Warp weaver (interlocking yarns)	10 percent maximum

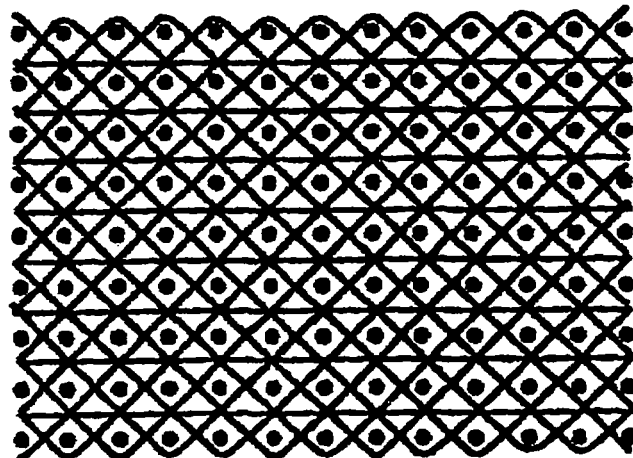
* Actual percentages in fabrics produced are listed in Appendix A data sheets.



Orthogonal
Through-the-Thickness



Layer-to-Layer
Angle Interlock



Through-the-Thickness
Angle Interlock

Figure 2.1-1. Interlock Woven Architectures

Table 2.1-3. 2D Braided Panels RTM'd at Boeing

2D braid type			Braid code	Preforms RTM'd at Boeing			
Braider yarn	% fixed yarn	Braid angle		1/16-in panels	1/8-in net	1/8-in panels	1/4-in panels
6K	45-55	70	SLL	6	22	16	19
15K	45-55	45	LLS	6	22	14	17
15K	45-55	70	LLL	2	16	8	7
15K	25-35	45	LSS	2	16	6	6
			Totals	16	76	44	49

- Notes: 1) 1/16 panels; 1/16-in thick x 12 in x 24 in (used for sandwich face sheets)
2) 1/8 net; 1/8-in thick x 1.5 in x 24 in
3) 1/8 panels; 1/8-in thick x 12 in x 24 in
4) 1/4 panels; 1/4-in thick x 12 in x 24 in

Table 2.1-4. 2D Braided Parts RTM'd at Fiber Innovations

Braid code	Preforms RTM'd at Fiber Innovations				
	1/4-in angle	1.25 OD x 30-in long	2.083 ID x 9-in long	2.083 ID x 30-in long	3.807 ID x 9-in long
SLL	3	5	10	5	5
LLS	3	5	10	5	5
LLL	2	2	10	2	5
LSS	2	2	10	2	5
Totals	10	14	40	14	20

- Notes: 1) 1/4 angle; 1/4-in thick L-shaped, 3 in x 3 in x 12-in long with 0.20-in radius
2) 1.25 OD x 30-in long; 1/8-in thick tube
3) 2.083 ID x 9-in long; 1/8-in thick tube
4) 2.083 ID x 30-in long; 1/8-in thick tube
5) 3.807 ID x 30-in long; 1/8-in thick tube

Table 2.1-5. Stitched Uniweave Panels RTM'd at Boeing

Stitch material (untwisted)	Stitches per inch	Stitch row spacing	Uniweave tow size	Quantity of preforms
S2-Glass	8	0.125	3K	2
S2-Glass	8	0.125	6K	2
Kevlar 29	4	0.250	6K	2
Kevlar 29	8	0.125	12K	2
Kevlar 29	8	0.125	6K	2

Note: All panels were 1/4-in thick x 24 in x 24 in

3.0 PROCESSING

Boeing's process of resin transfer molding uses a series of parallel plates with a picture frame style mold that forms the cavity. The mold is placed inside a heated-platen press for heating and clamping. Resin is injected into the mold with a heated pressure pot through four ports located at the center of each side of the picture frame. Resin infiltrates from the perimeter of the preform and is vented at the geometric center or center line. The preforms are dried under vacuum at 250°F for 2 hours in an air-circulating oven. On occasion, the preforms were dried inside the mold, for a similar time, and at a similar vacuum and temperature. The preforms are trimmed to fit into the cavity with a 1/8 in. to 1/4 in. margin around the perimeter for easy flow of resin.

There are several advantages in using perimeter injection of resin in RTM. Earlier work, where panels were infiltrated end to end, required elaborate steps to prevent resin blow-by. Resin blow-by occurs when resin preferentially flows around, rather than through, the preform and results in large, poorly infiltrated areas. Injecting resin along the perimeter and venting from the preform center eliminates blow-by. If the preform is rectangular, a series of small, pin hole venting ports are located along the center line. With perimeter injection, the preform's length and width tolerances are not important because the preform does not need to fit accurately into the mold cavity. Finally, perimeter infiltration requires shorter injection time because of shorter distances required for resin travel.

Shell's RSL-1895 two-part epoxy resin was injected into all panels. Prior to injection, each resin part was heated separately to 160°F to 180°F in an air-circulating oven. The mold temperature was held at 250°F. The resin was thoroughly mixed and placed into a warm injection pot. Prior to injection, the resin was degassed for 3 to 10 minutes at a vacuum of less than 30 in. Hg. The injection pressure was 16 to 30 psi, and was typically raised to 30 psi after injection was complete. Injection of the resin was monitored through nylon transfer lines. The resin-injection time and post-infiltration time was measured and recorded for each run. For each run, the mold temperature, resin injection temperature, and the pressure pot temperature were continually monitored and logged.

The versatility of the picture frame mold design allowed us to use the same tooling for a variety of preform sizes. Three different picture frames were used: (1) a small, single-cavity, 12-in. by 12-in. by 1.000-in-deep frame; (2) a large, single-cavity 24-in. by 24-in by 1.000-in-deep frame; and (3) a large dual-cavity 24-in by 24-in by 1.000-in-deep frame which used a divider plate 24 in by 24 in by 0.500 in (or 0.750 in).

An aluminum plunger plate and shims were inserted into the 1-in-deep picture frame to accurately bring the cavity to the target depth. Larger aluminum plates were stacked on top and bottom of the frame to form the injection and venting ports. By changing the sequence of plates, this mold could be assembled for the variety of RTM preforms: 24 in. by 24 in, 12 in by 24 in, 1.5 in by 24 in, and 12 in by 3.5 in by 1-in thick.

The silicone O-ring seals in the picture frame were thick enough so that an adequate seal was made when the mold was 0.001 to 0.020 in open. During resin injection only enough force (6 to 12 tons) was applied to close the mold partially, leaving a small gap while a good seal was maintained. This small gap in the mold allowed the preform to be infiltrated at a higher resin volume and a higher permeability. After the preform was infiltrated, the mold was completely closed using 20 to 60 tons force, and the excess resin was forced back into the pot through the injection port. This is a common technique used in RTM of simple parts. It allows low-pressure infiltration of low permeability preforms.

3.1 EXTENDED CURE CYCLE

Microcracking was observed predominantly in the interlock woven architectures (sect. 4.0). An extended cure cycle was developed to reduce the amount of microcracking. The extended cure cycle uses a lower cure temperature over an extended length of time, thereby reducing the temperature differential upon cooling. The extended cure cycle is: (1) 250°F mold temperature during resin injection; (2) hold 250°F for 8 to 12 hrs; (3) heat to 350°F, hold for 3.5 hrs; (4) slowly cool to 250°F and remove from mold hot. The standard cure cycle is: (1) 250°F mold temperature during resin injection; (2) heat to 300°F, hold for 30 min; (3) heat to 350°F, hold for 1.5 hrs; (4) cool slowly to room temperature and remove; (5) post-cure at 350°F for 2 hrs. The extended cure cycle was used on all of the interlock woven and stitched uniweave panels. The standard cure cycle was used on the braided preforms because microcracking was not prevalent in these architectures.

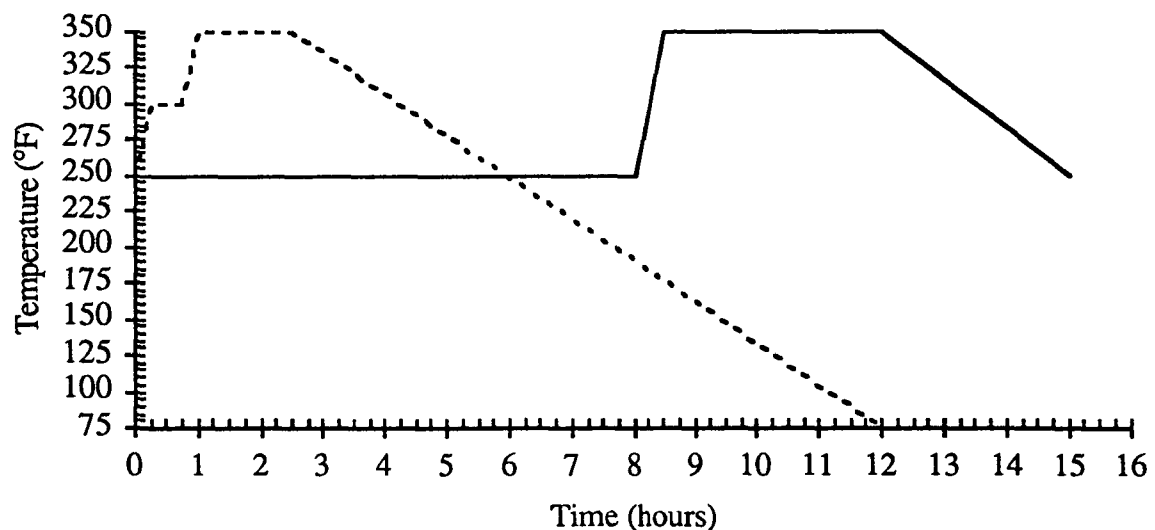


Figure 3.1-1 Shell RSL-1895/W cure cycle used in resin transfer molding. The extended cure cycle is shown as a solid line, and the standard cure cycle is shown as a dashed line. The extended cure cycle was used on all of the interlock woven and stitched uniweave panels. The standard cure cycle was used on the braided preforms.

3.2 STITCHED UNIWEAVE: 24 in BY 24 in PREFORM RTM

The largest preforms were the stitched uniweave panels. They were each nominally 24 in by 24 in and were molded two at a time in the dual cavity mold (fig. 3.2-1). The extended cure cycle was used for all stitched uniweave panels.

Two cavities are formed, top and bottom, by a divider plate (24 in by 24 in by 0.500 in) that rests on a lip inside the picture frame. The first preform is loaded into the bottom cavity, the divider plate is moved into place, and then the second preform is loaded into the top cavity. Two venting plates, each with a single vacuum port in the center, are located over each cavity. Shims are placed on both sides of the divider plate to give the proper cavity depth.

Resin flows into the stacked sequence of plates from the bottom. As it flows upward, it is distributed to each of the picture frame's four sides, where it infiltrates the preforms in both the top and bottom cavities at approximately the same time. Injection is stopped when resin is observed flowing in both of the venting lines.

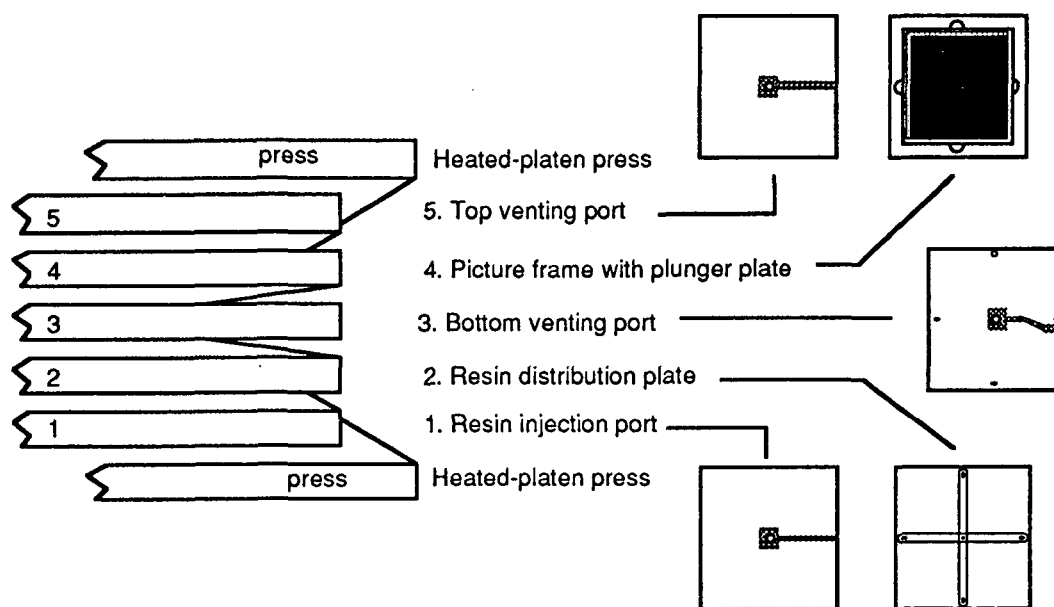


Figure 3.2-1 The dual cavity mold setup for two 24 in. by 24 in. preforms. Two cavities are formed, top and bottom, by a divider plate (24 in by 24 in by 0.500 in.) that rests on a lip inside the picture frame. Two venting plates, each with a single vacuum port in the center, are located over each cavity. Shims are placed on both sides of the divider plate to give the proper cavity depth. Resin flows into the stacked sequence of plates from the bottom. As it flows upward, it is distributed to each of the picture frame's four sides, where it infiltrates both top and bottom preforms at approximately the same rate.

3.3 BRAIDED AND INTERLOCK WOVEN: 12 in BY 24 in PREFORM RTM

The preforms were nominally 12 in by 24 in and included the 2-D braided and the interlock woven architectures. The majority of these panels were molded four at a time, using the dual cavity picture frame previously discussed (fig. 3.3-1). Two venting plates (24 in by 24 in) provided a series of five to seven small venting ports along the center line of each preform in both the top and bottom cavities. Center-line venting gave excellent results when molding rectangular preforms. Panels fabricated before building the dual-cavity mold were either molded side by side in a single-cavity configuration, or one at a time in a single-mold configuration.

The interlock woven architectures were molded with the extended cure cycle. The braided architectures were molded with the standard cure cycle (sect. 3.1).

3.4 BRAIDED NET-SHAPE: 1.5 in BY 24 in PREFORM RTM

Net-shape braided preforms were nominally 1.5 in wide by 24 in long by 1/8 in thick, and were molded in a single-cavity mold using the standard cure cycle, (fig. 3.4-1). A specialized plunger plate was designed and fabricated to give the picture frame mold 12 cavities, each 12 in long by 1.50 in wide. It was found necessary to taper the cavity sides 5 deg. so that the parts would release from the mold. A shim placed on top of each cavity took up the excess cavity depth. A 12-port venting plate was fabricated. Each port was located at the top-center of each one of the 12 cavities. Resin flowed from both ends of the preform toward the center venting port.

This method of injection proved to be successful. We were able to process 12 parts in a single run, significantly reducing our labor hours. Resin blow-by was eliminated by locating the venting ports at the center of the part, and by spacing the cavities close together. Some difficulty was encountered when loading the preforms into the mold. The preforms did not fit exactly into the cavities and would get pinched between the cavity and the venting plate. To remedy this, the preforms were dried into the cavities against the plunger plate using a vacuum bag and oven. Drying would consolidate the preforms to the exact cavity size and prevent fiber pinching.

3.5 INTERLOCK WOVEN AND 3D BRAID: ANGLE RTM

A steel tool was built for 90-deg-angle panel resin transfer molding (fig. 3.5-1). The tool had a cavity depth of 0.250 in; it formed an inside radius of 0.200 in and an outside radius of 0.45 in. The cavity was 12.0-in in length. The distance from the radius to the long edge was 3.75 in. During injection, the mold was oriented with the 90 deg. bend on the top. Resin was injected from the perimeter, just as with flat panels. Three pinhole venting ports were located on the outside radius to provide vacuum.

This mold configuration provided excellent results. All panels were completely infiltrated, showing no visual areas of high porosity. All angled cross-section panels processed by Boeing were either an interlock woven or 3D braid architecture. The extended cure cycle was used in the interlock woven panels.

The 3D braided panel (provided by Quadrax) required shimming to give the appropriate cavity depth. The shims wrapped around the outside radius and had holes to accommodate the venting ports. During the injection of this particular part, the venting ports were inadvertently closed off by a sealant used to seal the shims against the mold. As a result, approximately half the panel centered around the radius was poorly infiltrated with resin. The panel was inserted back into the mold and re-injected with resin. The resin flowed nicely into the dry areas, resulting in a well-infiltrated panel. The first injection used the extended cure cycle. However, in order to reduce the processing time, the second injection used the standard cure cycle.

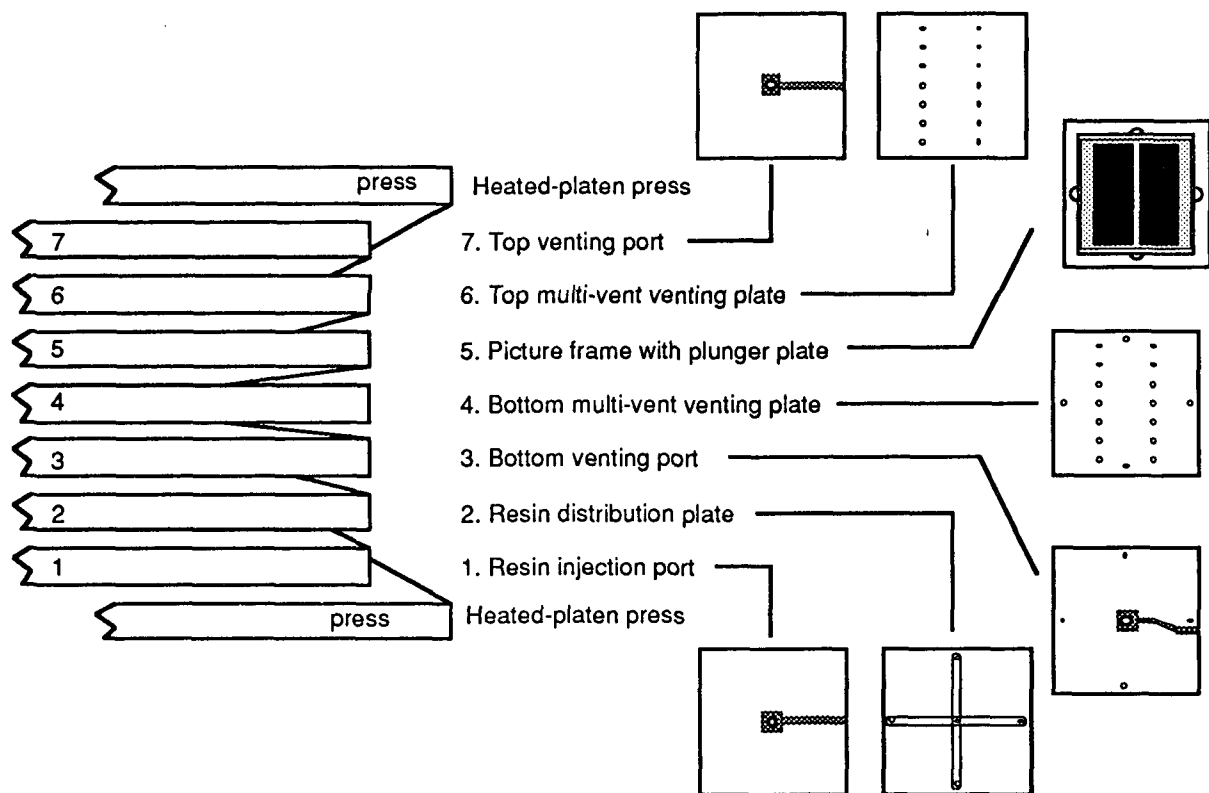


Figure 3.3.1 The dual cavity mold set-up for four 12 in by 24 in preforms. Two venting plates (24 in by 24 in) provide two series of five to seven small venting ports along the center line of each preform in both the top and bottom cavities. Center-line venting gave excellent results when molding rectangular preforms. The preforms that were nominally 12 in by 24 in included the 2-D braided and the interlock-woven architectures. The majority of these panels were molded four at a time, using the dual cavity picture frame. Panels fabricated before building this mold were either molded side by side in a single-cavity configuration, or one at a time in a similar single-cavity configuration

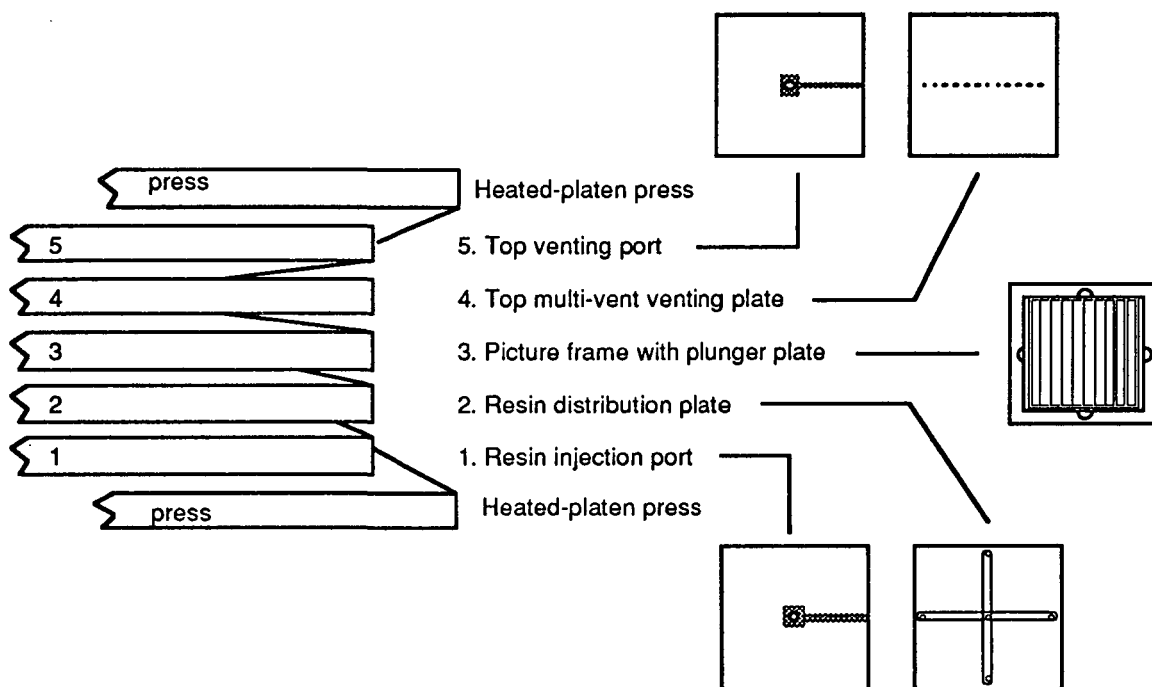


Figure 3.4-1 Net-shape braided preforms were nominally 1.5 in by 24 in by 1/8 in, and were molded in a picture-frame mold using the standard cure cycle. A specialized plunger plate was designed and fabricated to give the picture-frame mold 12 cavities, each 12 in long by 1.50 in wide. It was found necessary to taper the cavity sides 5 deg so that the parts would release from the mold. A shim placed on top of each cavity took up the excess cavity depth. A venting plate was fabricated with 12 ports located at the top-center of each one of the 12 cavities. Resin flowed from both ends of the preform toward the center venting port.

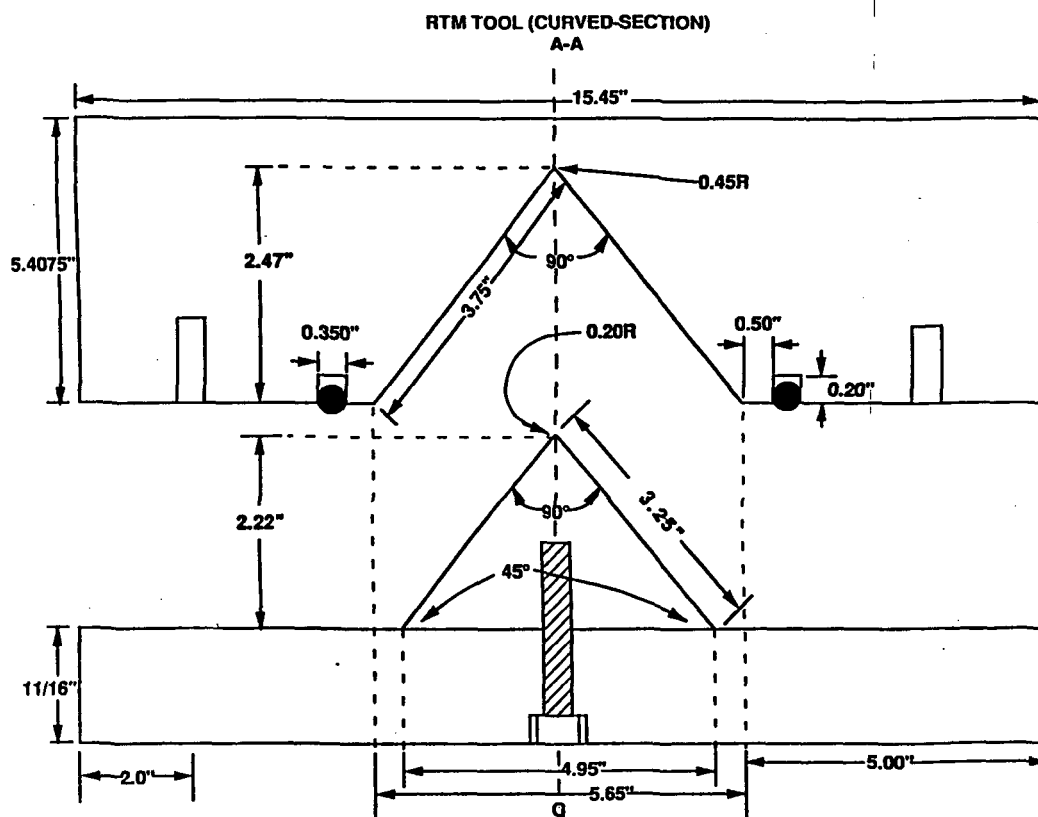


Figure 3.5-1 A steel tool was built for 90 deg angle panel resin transfer molding. The tool gives a part thickness of 0.250 in; it forms an inside radius of 0.200 in and an outside radius of 0.45 in. The cavity was 12.0 in. in length. During injection, the mold was oriented with the 90 deg bend on the top. Resin was injected from the perimeter, just as with flat panels. Three pinhole venting ports were located on the outside radius to provide vacuum.

The reprocessing of the 3D braided Quadrax panel demonstrated the potential for repair of textile composites. Defects may result from the manufacturing process or from impacts in the field. The repair of manufacturing defects could be accomplished by reinsertion in the mold for back infiltration. Small defects of dry fiber may be repaired by a method whereby resin is injected into the dry fiber between two plates. It may be possible to repair impact damage, characterized by minimal fiber breakage, by dissolving the damaged resin with an acid wash and then infiltrate new resin between tow plates. Larger damaged areas may require the replacement of a portion of the textile composite, which may be resin transfer molded in place.

3.6 INTERLOCK WOVEN: 1-IN-THICK CROSS SECTION RTM

The 12-in by 12-in by 1 in picture frame was used to RTM interlock woven panels nominally 1 in thick by 3.25 in wide by 11.75 in long (fig. 3.6-1). These panels were molded to net shape; the top, bottom, right and left sides were formed by the mold (fig. 3.6-2). Two aluminum blocks, each 2.25 in wide by 0.990 in thick by 11.90 in long, formed the right and left sides of the mold. Elastic silicon sheeting, 0.202 in thick, filled the excess volume and transposed the force from the press to transverse forces against the aluminum blocks. The amount of silicon sheeting was precisely calculated and weighed-out to give the optimal transverse forces. A thermocouple was passed through one of the aluminum blocks and rested against the side of the preform. This thermocouple was used to monitor the resin exotherm. Resin infiltrated from opposite ends toward a single venting port located at the center of the top side.

The first run used scrap preform material and served to demonstrate the mold concept and to determine the processing parameters. A thermocouple was located inside the center of the laminate to monitor any temperature excursions due to the resin exotherm. In order to avoid an uncontrolled exotherm, the cure cycle was modified for a longer cure time at a lower temperature. Using this cure cycle, it was found that the resin exotherm did not produce any significant temperature excursions. As a result, we modified the cure cycle for all 1-in-thick panels molded in this fashion as follows: (1) 225°F mold temperature during resin injection; (2) hold at 225°F for 2 hrs; (3) heat to 250°F, hold 8 to 12 hrs; (4) heat to 350°F, hold 3.5 hrs; and (5) slow cool to room temperature and remove.

3.7 RESIN TRANSFER MOLDING PROCESSING PROCEDURE

- 3.7.1 Dry preforms using a vacuum bag and oven for 2 hours at 250°F. As an alternative, the preforms may be dried in the mold under vacuum for 2 hours at 250°F.
- 3.7.2 Trim each preform to fit into mold with 1/8 in to 1/4 in margin around each preform to allow easy flow of resin around the perimeter. Remove all excess fibers from the surface of each preform. Remove all tape from the preform surfaces.
- 3.7.3 Assemble mold according to engineering instructions. Insert preforms, taking care to center each preform in the cavity. Place shims, if required, against the plunger plate (never against the venting plate). Close the mold, taking care that the shim(s) do not get pinched between the picture frame and the venting plate.
- 3.7.4 Weigh resin per engineering instructions. Place each resin part in a separate 1-gal or 1-qt paint can. Heat resin in oven per engineering instructions. Allow 1 to 3 hours for heating. Check that the resin temperature is within tolerance before proceeding to inject.

- 3.7.5 Assemble blanket heater onto pressure pot. Connect injection hose to press. Clamp injection hose. Connect vacuum hose from mold to vacuum trap. Heat pressure pot per engineering instructions. Assemble regulator and pressure hose.
- 3.7.6 Assemble vacuum apparatus for resin degassing. Resin degassing may be done either in a vacuum bell jar or in the resin pot itself.
- 3.7.7 Assemble temperature data logger, using one thermocouple inside the mold, one thermocouple in the resin inside the pressure pot, and two thermocouples in the heater blanket on the pot.
- 3.7.8 Place can containing the first component into the pressure pot. Pour the second component into the first. Mix both resin components together. Stir thoroughly, ensuring good mixing of both components. Secure the top of the pressure pot in place.
- 3.7.9 Pressurize the pot per engineering instructions. Begin resin injection by removing injection hose clamp. Start timer to measure injection time.
- 3.7.10 Monitor resin pot temperature. If resin begins auto-heating, an uncontrolled exotherm condition exists. Terminate run and follow procedures for an uncontrolled exotherm.
- 3.7.11 Look for bubbles in the injection line. Bubbles in the injection line indicate an inadequate amount of resin. Terminate the run and notify the responsible engineer.
- 3.7.12 Look for resin in the vacuum line(s). Record the injection time from when you removed the hose clamp to when you first observed resin in the vacuum line(s). Continue injecting resin until a steady stream of resin is observed coming from the vacuum line(s). Record the additional injection time as resin injection time after infiltration.
- 3.7.13 Clamp the vacuum line(s). Remove the heating blankets from the pressure pot.
- 3.7.14 Increase the press force per engineering instructions. The pot resin temperature may increase because of resin flow back into the pot. Although this is not exotherm condition, monitor the pot temperature closely for auto-heating.
- 3.7.15 Increase pot pressure per engineering instructions.
- 3.7.16 Set press temperature and begin the cure cycle per engineering instructions.
- 3.7.17 Ensure the pot resin temperature is steadily decreasing before leaving unattended.

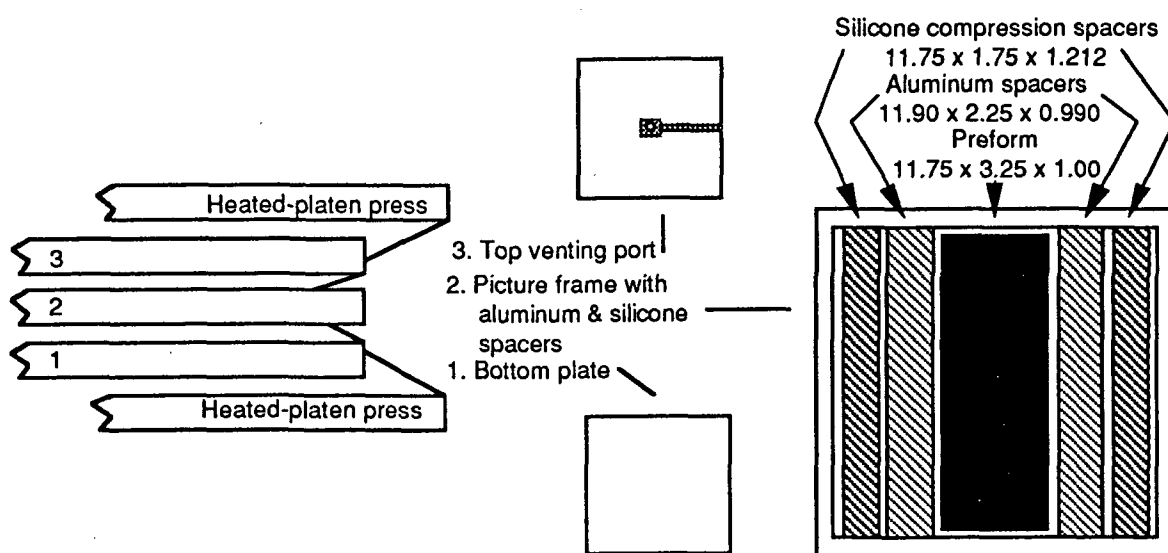


Figure 3.6-1 The 12-in by 12-in by 1-in picture frame was used to RTM interlock woven panels nominally 1-in thick by 3.25-in wide by 11.75-in long. These panels were molded to net shape; the top, bottom, right, and left sides were formed by the mold. Two aluminum blocks, each 2.25 in wide by 0.990-in thick by 11.9-in long, formed the right and left sides of the mold. Elastic silicon sheeting, 0.202-in thick, filled the excess volume and transposed the force from the press to transverse forces against the aluminum blocks. A thermocouple was passed through one of the aluminum blocks and rested against the side of the preform.

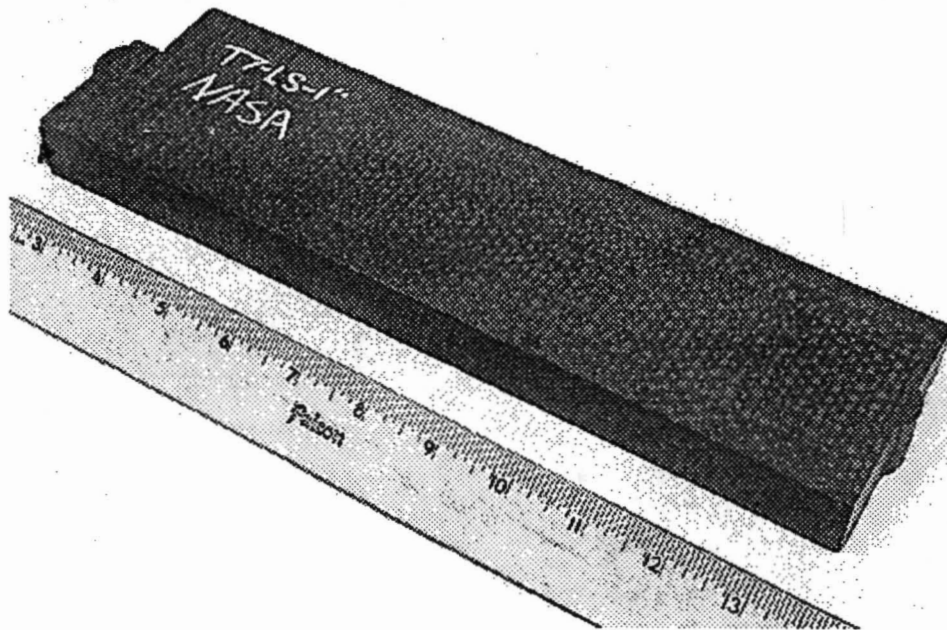


Figure 3.6-2 The 1 in thick interlock woven panels (1.000 by 3.25 by 12) were molded to net shape. The top, bottom, right and left sides were formed by the mold. Resin infiltrated from opposite ends towards a single venting port located at the center of the laminate. Two aluminum blocks and elastic silicon sheeting filled the excess volume of the mold and transposed the press forces to transverse forces against the the part. A modified cure cycle was used to prevent temperature excursions from the resin exotherm.

3.8 SUMMARY

The simple picture-frame mold design allowed the processing of many different sizes of flat panels in a single set of tooling. Resin was injected into the mold with a heated pressure pot. Prior to injection, each component of Shell's RSL-1895 resin was heated separately in an oven to the injection temperature. The two components were then mixed together moments before injection into the panel. The resin flowed from the pot to a runner system which distributed resin around the entire perimeter of each part. Small ports located at the geometric center line of each part provided good venting.

The method of injecting resin from the perimeter was highly successful because it completely eliminates resin blow-by. With perimeter injection, the preform's length and width tolerances are not important because the preform does not need to fit snugly into the mold cavity. The seals in the mold allowed a 0.001-in to 0.020-in gap during resin injection, increasing the permeability of the preform and decreasing the injection time. The mold was completely closed after infiltration. All flat panels were processed in the picture-frame mold. Although a special tool was needed to fabricate the curved panels, the same injection and venting concept proved successful.

4.0 PHOTOMICROSCOPY AND MICROCRACKING

During the early stages of this program, microcracking was observed in some of the photomicrographs of the interlock woven architectures. The fabrication of panels was halted for a period of time to determine the cause and extent of the microcracking. As a result of the microcracking investigation, a lower-temperature, extended-time cure cycle was used on all subsequent interlock woven processing. The first interlock woven panels delivered to NASA were processed with the standard cure cycle. After the conclusion of the microcracking study, interlock woven panels delivered to NASA, comprising the majority of these panels, were marked as being processed with the extended cure cycle.

Microcracking can be caused by a number of architectural, processing, or environmental circumstances. Associated with the curing of any resin is a corresponding chemical shrinkage from the polymerization reaction. Shell's RSL-1895 (Shell Epon Curing Agent W) resin changes in specific gravity from a value of 1.14 before cure (at room temperature) to 1.18 after cure. This is one source of internal stresses that may be exhibited as microcracking. Another source is from cooling to room temperature after processing. This creates internal stresses from the thermal expansion/contraction mismatch between the resin and the fiber.

The preform architecture will restrain cure shrinkage in one, two, or three directions, adding to the buildup of internal stresses. Three-dimensional architectures will restrict resin contraction in all three directions, while two-dimensional architectures will restrict contraction in two directions; the difference translates into a significant increase in internal stresses. In addition, three-dimensional architectures will form resin pockets at the intersection of fiber bundles. Microcracks often form in these resin pockets within a laminate.

The processing conditions will effect the internal stresses in a composite, and thereby effect microcracking. Curing at a lower temperature for a longer time may reduce microcracking. A lower cure temperature will reduce resin/matrix thermal contraction mismatch, and thus reduce microcracking. An additional amount of microcracking may occur during post-cure when the glass transition temperature increases and the resin becomes more brittle. The thermal expansion/contraction mismatch between the overall part and the tool may also contribute to microcracking. Tooling made of steel or aluminum can apply a significant amount of force on a composite part during cool down from cure. Aside from processing conditions, environmental effects such as any combination of fatigue, thermal cycling, thermal shock or exposure to solvents or aircraft fluids, may induce microcracking or worsen existing microcracking.

Microcracking was first observed in cross-sectional photomicrographs (25x) of the interlock woven architectures (fig. 4.0-1). The cracks can be observed in any one of the cross-sectional planes, be it the x, y, or z plane, although they can be more prevalent in one plane than another (figs. 4.0-2, 4.0-3). Microcracking can be seen in resin pockets and through fiber bundles, propagating between fibers. In all cases, microcracking did not fracture or break fibers.

Microcracking is observed in the photomicrographs as narrow, angular black lines, approximately the length of a fiber bundle. Carbon-fiber bundles are shown on axis as elliptical elements of gray/light-gray texture, and off axis as a series gray/light-gray textured parallel lines (glass fiber bundles are much lighter and may be more difficult to see). There is often resin-rich areas within or between fiber bundles which is seen in a gray to dark-gray tone, that should not be confused with microcracks. Porosity or voids are the same black color as microcracks, but are usually rounded and have significant thickness and width (compared to microcracks). Scratches and polishing aberrations are nearly straight and will not follow any architectural features, unlike microcracks.

An extended cure cycle was developed to minimize microcracking in the three-dimensionally reinforced laminates. The extended cure cycle uses a lower cure temperature

over an extended length of time, thereby reducing the temperature differential upon cooling. The extended cure cycle is: (1) 250°F mold temperature during resin injection; (2) hold 250°F for 8 to 12 hrs; (3) heat to 350°F, hold for 3.5 hrs; (4) slowly cool to 250°F and remove from mold hot. The standard cure cycle is: (1) 250°F mold temperature during resin injection; (2) heat to 300°F, hold for 30 min; (3) heat to 350°F, hold for 1.5 hrs; (4) cool slowly to room temperature and remove; and (5) post-cure at 350°F for 2 hrs. The extended cure cycle was used on all subsequent interlock woven and stitched uniweave panels. It was found to reduce, but not eliminate, microcracking in the interlock woven panels (fig. 4.0-4).

The amount of microcracking is very much dependent on the characteristics of the resin. In an attempt to reduce or eliminate microcracking, we investigated British Petroleum's E905L resin, and 3M's PR-500. Six laminates, 6 in by 6 in by 1/4 in nominal, were fabricated with the BP E905L resin using the interlock woven architectures (LS-1, OS-1, and TS-1) and the braided architectures (SLL, LLL, and LSS). British Petroleum's standard 350°F cure cycle was used in processing each panel. Photomicrographs showed a moderate amount of microcracking occurring in the OS-1 architecture and a minimal amount occurring in the TS-1 architecture. The other architectures had virtually no microcracking. The study was repeated using Shell's RSL-1895 resin with the extended cure cycle, all other factors being the same. With the extended cure cycle, it was found that the Shell resin produced the same results as the BP resin; microcracking was observed in the OS-1 and TS-1 architectures.

Continuing this investigation, the 3M PR-500 resin was injected into a single OS-1 panel. The orthogonal interlock architecture (OS-1 and OS-2) were the most susceptible to microcracking. It was found that the PR-500 resin microcracked to the same extent as did the BP E905L and the Shell RSL-1895 resin. Microcracking in the orthogonal interlock panels could be reduced but not eliminated, given our current set of materials. It was decided to continue processing of the interlock woven panels using Shell's RSL-1895 resin and the extended cure cycle. The braided architectures were processed with the RSL-1895 resin and the standard cure cycle.

It was not necessary to use the extended cure cycle with the braided architectures because microcracking was not prevalent in these panels (fig. 4.0-5). Panels molded from the braided architectures did not microcrack to the same extent as the interlock woven architectures. Very minimal or no microcracking was observed in all these photomicrographs. Microcracking was minimal because the large resin pockets do not form in these architectures, and cure shrinkage is restricted in two directions.

However, using the standard cure cycle, Fiber Innovations observed a moderate amount of microcracking in their LLL 2D-braided tubes. As a result, Fiber Innovations chose to use an extended cure cycle in the RTM of their LLL braided tubes (fig. 4.0-6). They independently developed an extended cure cycle similar to our own extended cure cycle. Their extended cure cycle differs from ours by a 270°F hold (instead of 250°F) for 8 hours.

A photomicrograph of the 90 deg angled-cross-section laminate (layer-to-layer, interlock woven LS-1) is given in figure 4.0-7 (showing the curved section only). In our first attempt at this process, a large amount of porosity at the fiber-bundle intersections (where resin normally pools) was observed, as shown in figure 4.0-7. The problem was solved by introducing additional venting ports along the outside radius. Subsequent curved laminates had low porosity, as evidenced by TTU inspection. Bending the preforms over the 90 deg angle did not induce any observable fiber damage. The standard cure cycle was used in the processing of this laminate. The extended cure cycle was used on all subsequent laminates. The photomicrograph shows moderate to extensive microcracking, which is typical with this cure cycle and this architecture. Photomicrographs of Fiber Innovation's braided, 90-deg-angled cross-section laminate (LSS and LLS architectures) showed little or no microcracking (the photomicrographs are not included in this report).

The extended cure cycle was used in the processing of the stitched uniweave panels. A photomicrograph of the 6K-glass stitched panel, 1/8-in stitch spacing, is shown in figure 4.0-8 (50x). The glass stitch is barely discernible from the resin because of the transparent qualities of glass. The Kevlar® needle thread is shown in the loop of the glass lock stitch. Little microcracking and porosity was observed, and was limited to areas near the stitch where resin pooling occurred. This was the only stitched uniweave panel photomicrographed.

Figure 4.0-9 shows the photomicrograph of a 1-in-thick, layer-to-layer interlock woven panel, fabricated for analysis at the University of Delaware (6x). The extended cure cycle was used in the processing of this panel. An extensive amount of microcracking and little porosity was observed. The cracks run top to bottom, occurring regularly in the thick warp yarns. In comparing different architectures, the frequency of microcracking appeared to increase with the thickness of yarns.

4.1 SUMMARY

Microcracking occurred predominantly in the interlock woven architectures. Of the six interlock woven architectures, microcracking occurred most often in the orthogonal interlock materials, OS-1 and OS-2. Microcracking was probably caused by chemical shrinkage in the polymerization process, fiber/matrix thermal contraction mismatch during cool-down, and the restraints to resin shrinkage applied by the architecture during the cure process. We were able to reduce the amount of microcracking by using a lower temperature (250°F), extended-time cure cycle. 3M's PR-500 and British Petroleum's E905L resin system microcracked to the same extent as Shell's RSL-1895 with the extended cure cycle. Microcracking in the orthogonal interlock panels could not be eliminated, given our current set of materials. Shell's RSL-1895 resin and the extended cure cycle were used in the fabrication of all subsequent interlock woven and stitched uniweave panels (including the 3D braided Quadrax panels). It was not necessary to use the extended cure cycle in the 2D braided architectures because microcracking was not prevalent in these panels. However, Fiber Innovations used their extended cure cycle (270°F cure) in the fabrication of the LLL braided tubes. The photomicrographs shown in this section were selected to show specific cases of microcracking and porosity. They are not typical of the panels as a whole. A total of 46 photomicrographs were taken of textile composites in our original study. These photomicrographs can be found in our informal report (ref. 5).

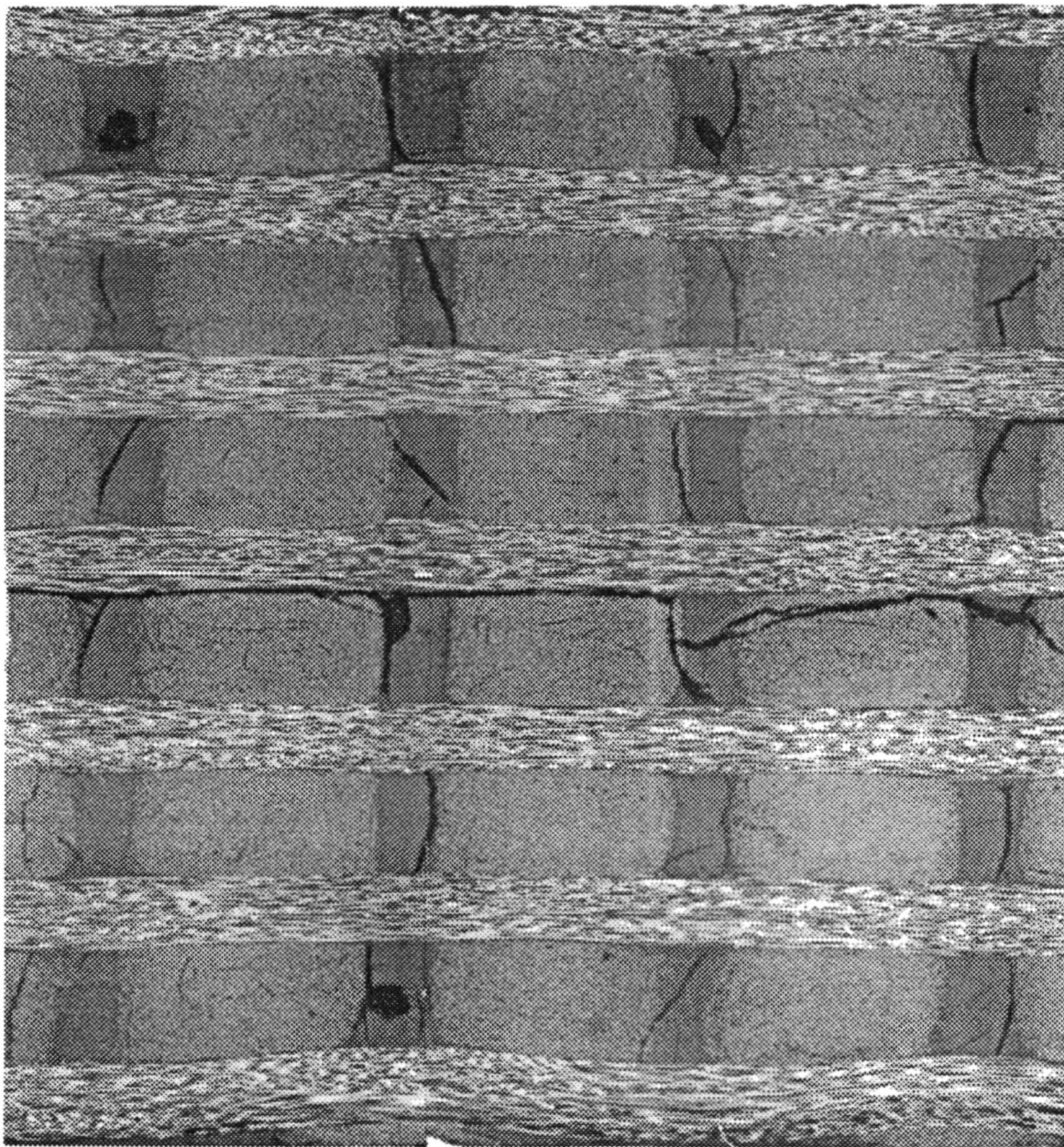


Figure 4.0-1 Photomicrograph showing microcracking in the x-plane of the orthogonal interlock woven architecture, OS-2 (25x). Microcracking was first observed in cross-sectional photomicrographs of the interlock woven architectures. The cracks can be observed in any one of the cross-sectional planes, be it the x, y or z plane, although it can more prevalent in one plane more than another, (fig.s 4.0-2, 4.0-3). Microcracking can be seen in resin pockets and through fiber bundles, propagating between fibers. In all cases, microcracking did not fracture or break fibers. The porosity in this panel is not indicative of other panels as a whole. The standard cure cycle was used in processing. This photomicrograph was taken before post-cure.

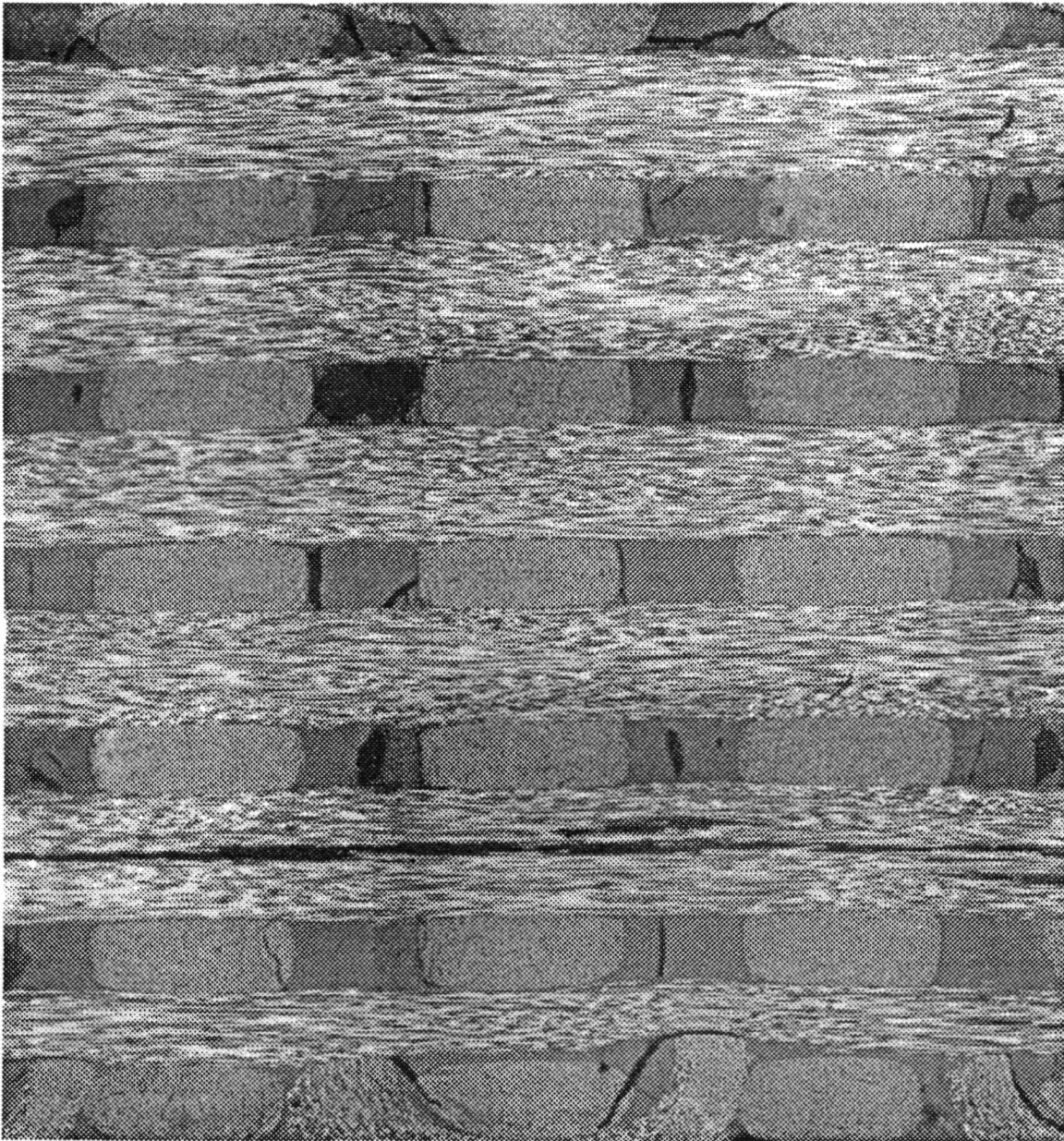


Figure 4.0-2 The y-plane of the orthogonal interlock woven architecture, OS-2 (25x). Microcracking is observed in the photomicrographs as narrow, angular black lines, approximately the length of a fiber bundle. Carbon fiber bundles are shown on axis as square or elliptical elements of gray/light-gray texture, and off axis as a series gray/light-gray textured parallel lines. Porosity or voids are the same black color as microcracks, but are rounded and have significant thickness and width (compared to microcracks). Scratches and polishing aberrations are very-nearly straight, and will not follow any architectural features; unlike microcracks. The porosity in this panel is not indicative of other panels as a whole. The standard cure cycle was used in processing. This photomicrograph was taken before post-cure.

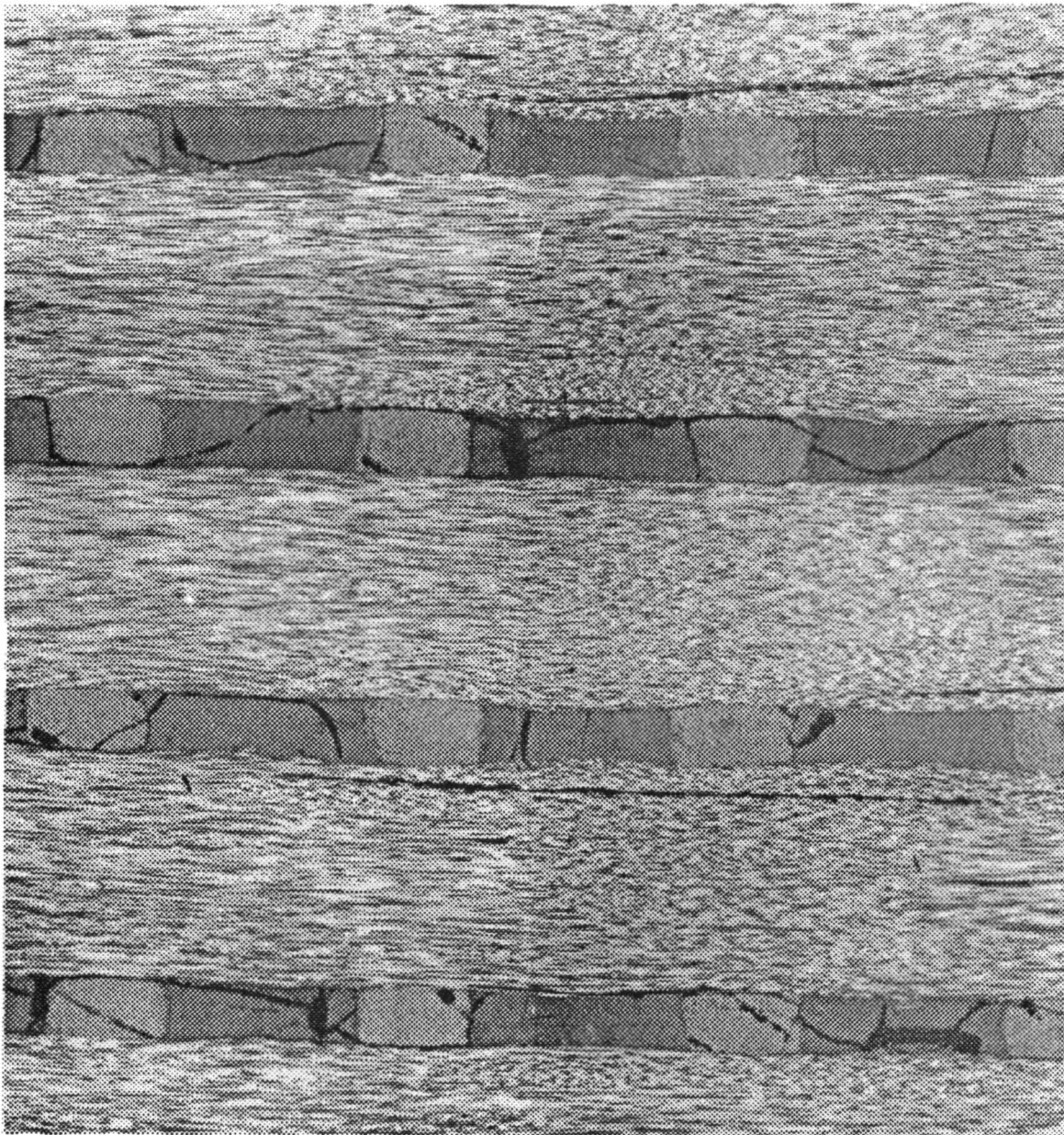


Figure 4.0-3 The z-plane of the orthogonal interlock woven architecture, OS-2 (25x). The 3K weaver or through-thickness yarns (z-axis) are shown as small squares evenly spaced throughout the architecture. The 12K warp yarns (x-axis) run the length of the photomicrograph. Because of the section location, the 6K weft (y-axis) yarns are below the plane of the photograph, and are not visible. The porosity in this panel is not indicative of other panels as a whole. The standard cure cycle was used in processing. This photomicrograph was taken before post-cure.

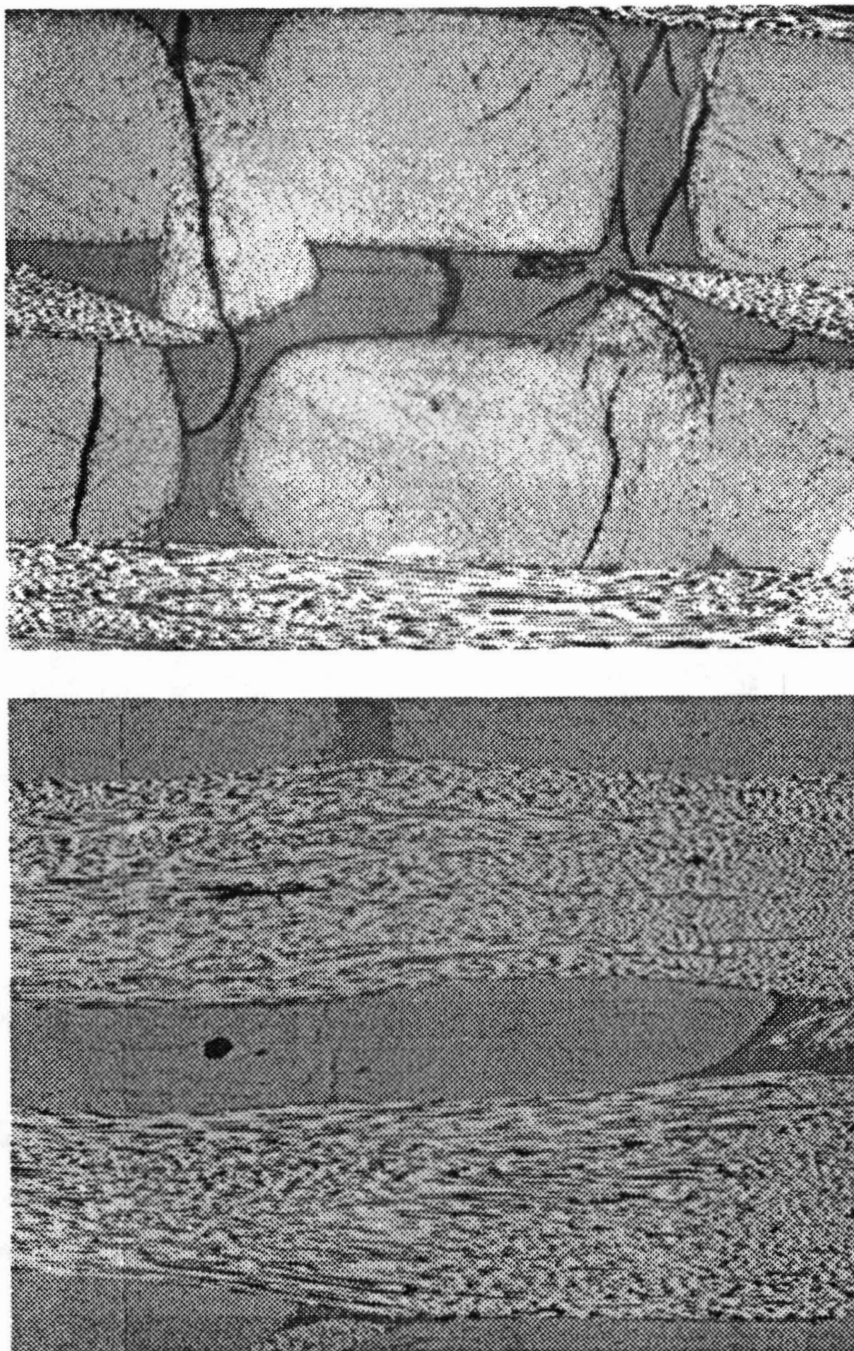


Figure 4.0-4 Photomicrograph of the through-thickness, angled interlock (TS-1) architecture fabricated with the standard cure cycle (top) and with the extended cure cycle (bottom), (25x). An extended cure cycle was developed to minimize microcracking in the three-dimensionally reinforced laminates. The extended cure cycle uses a lower cure temperature for an extended length of time, thereby reducing the temperature differential upon cooling. The extended cure cycle was used on all subsequent interlock woven and stitched uniweave panels. It was found to reduce, but not eliminate, microcracking in the interlock woven panels.



Figure 4.0-5 Photomicrograph of an LLL two-dimensional, braided, flat panel, standard cure cycle (25x). It was not necessary to use the extended cure cycle with the braided architectures because microcracking was not prevalent in these preforms. The resin rich areas between and within fiber bundles, shown in dark gray, should not be confused with microcracks. Fiber innovations used an extended cure cycle in the fabrication of the LLL tubes, (fig. 4.0-6



Figure 4.0-6 Photomicrograph of a two-dimensional, braided LLL tube fabricated by Fiber Innovations (25x). Fiber Innovations used an extended cure cycle in the RTM of the LLL braided tubes. The standard cure cycle produced a moderate amount of microcracking, mostly in the LLL architecture. As a result, Fiber Innovations developed and implemented an extended cure cycle similar to our own extended cure cycle. Their extended cure cycle differs from ours by a 270°F hold (instead of a 250°F) for 8 hours.

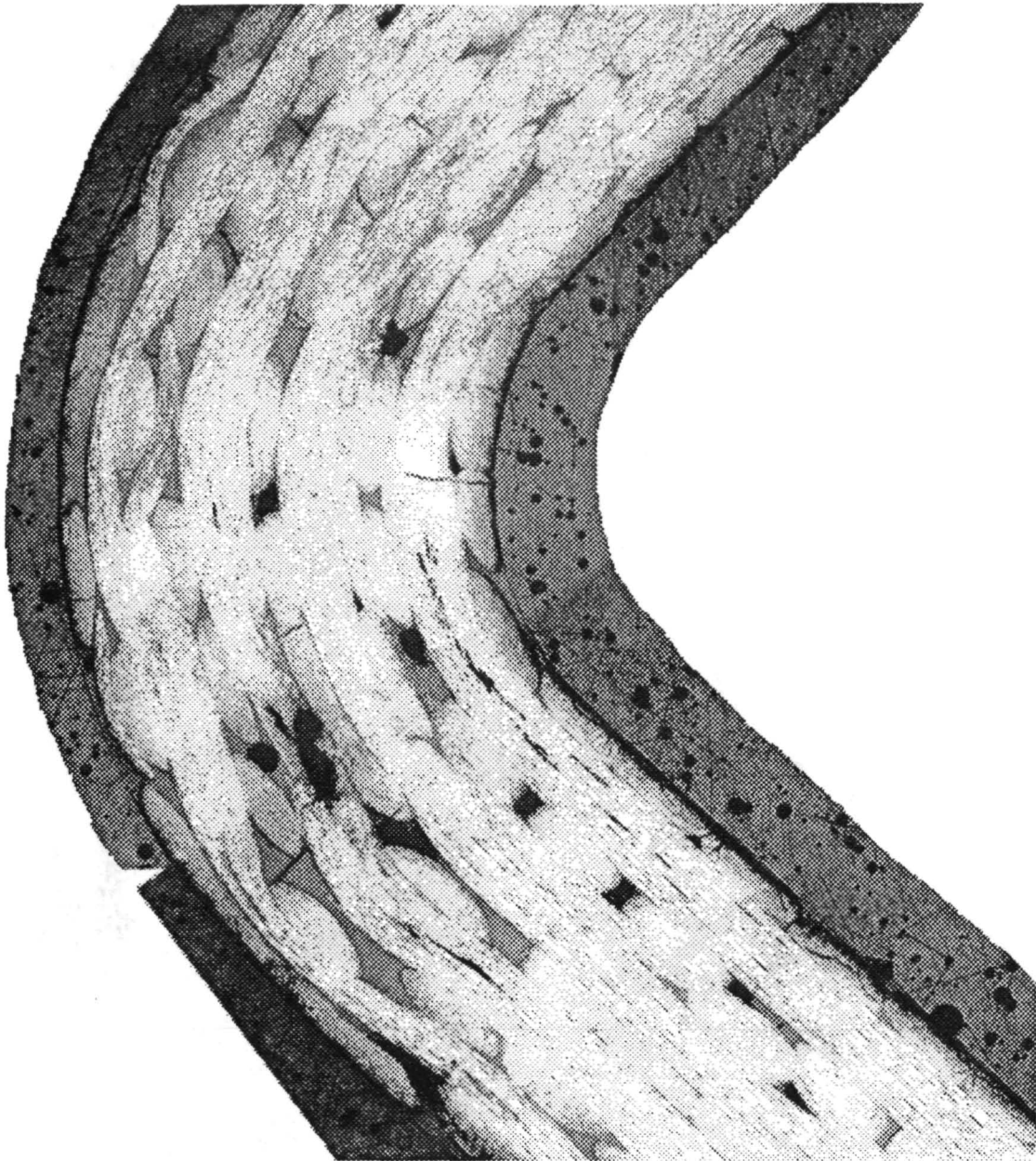


Figure 4.0-7 Photomicrograph showing the curved portion of a 90° angled-cross-section laminate (layer-to-layer, interlock woven LS-1). This was our first attempt with this process. A large amount of porosity at the fiber-bundle intersections, where resin normally pools is shown. The problem was solved by introducing additional venting ports along the outside radius. Subsequent curved laminates had low porosity, evidenced by TTU inspection. Bending the preforms over the 90° angle did not induce any observable fiber damage on the LS-1 architecture. The standard cure cycle was used in the processing of this laminate; the extended cure cycle was used on all subsequent laminates. The amount of microcracking and porosity is not typical of the subsequent laminates.

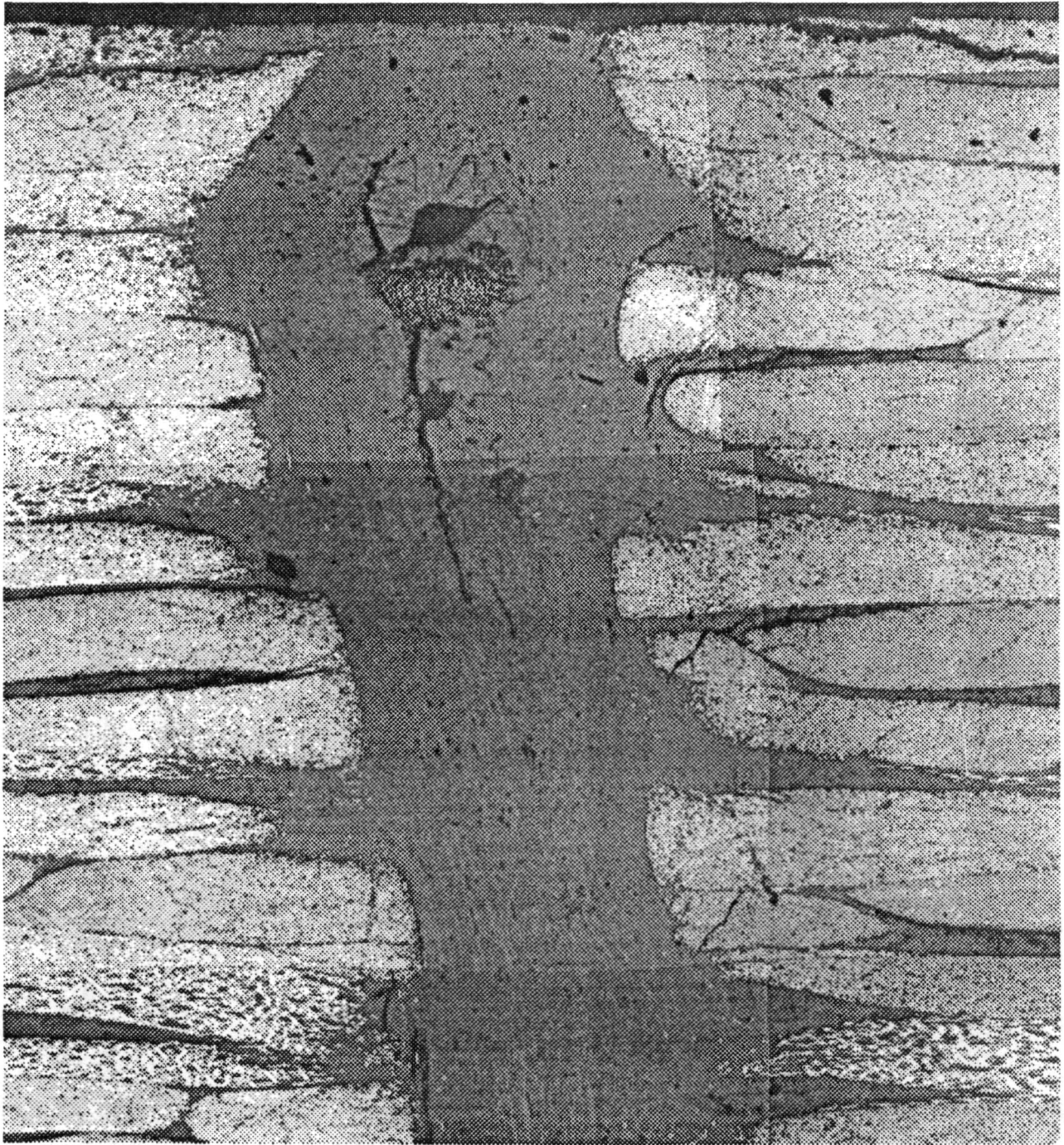


Figure 4.0-8 A photomicrograph of the 6K-glass stitched panel, 1/8 inch stitch spacing (50x). The extended cure cycle was used in the processing of all stitched uniweave panels. The glass stitch is barely discernable from the resin because of the transparent qualities of glass. The Kevlar® needle thread is shown in the loop of the glass lock stitch. Little microcracking and porosity was observed, being isolated to areas near the stitch where resin pooling occurred. This was the only stitched uniweave panel photomicrographed.

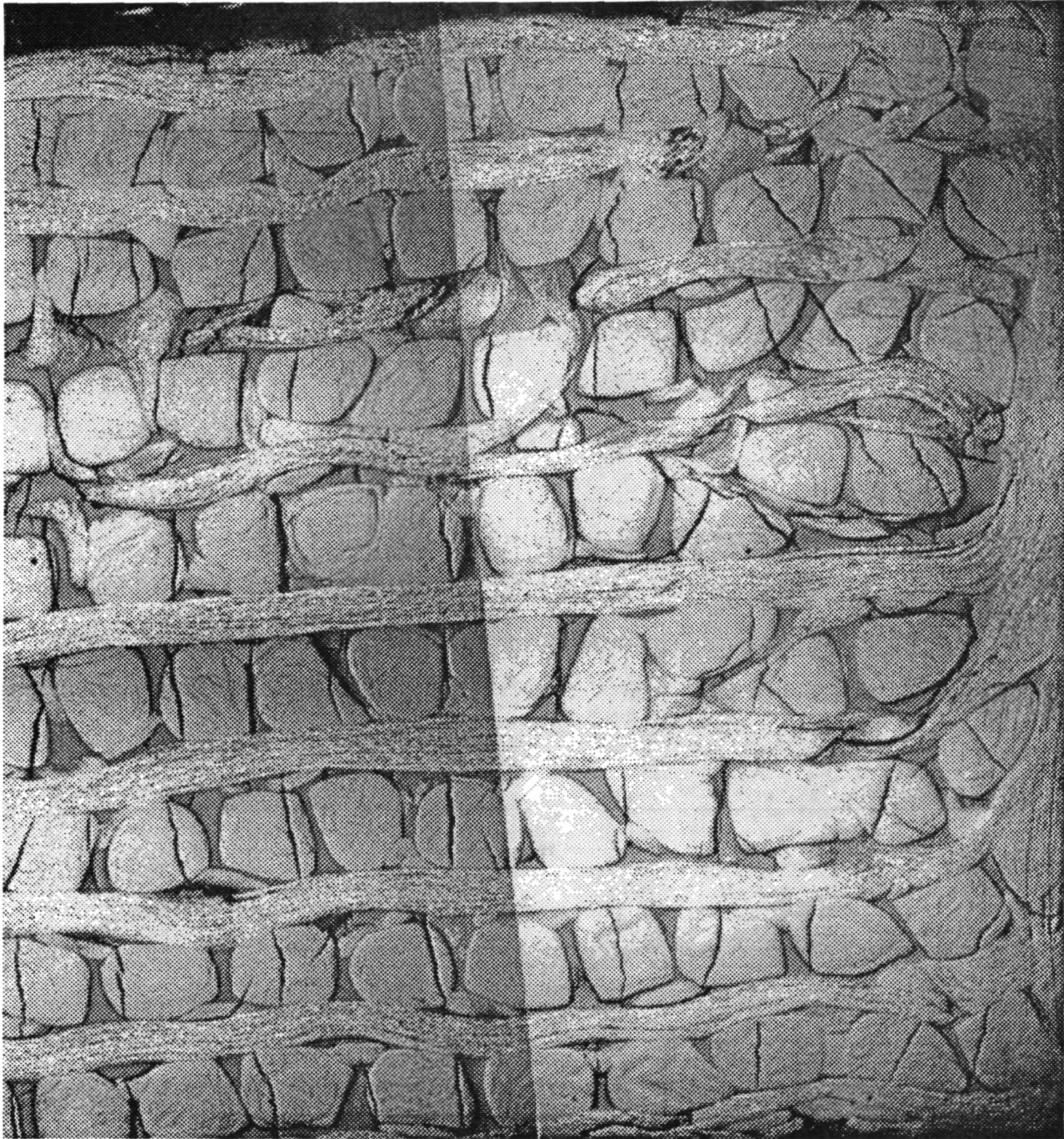


Figure 4.0-9 Photomicrograph of a one-inch thick, layer to layer interlock woven panel, fabricated for analysis at the University of Delaware (6x). The extended cure cycle was used in the processing of this panel. An extensive amount of microcracking, and little porosity is observed. The cracks run top to bottom, occurring regularly in the the thick warp yarns

5.0 NONDESTRUCTIVE INSPECTION OF TEXTILE COMPOSITES

In order to use textile composites in primary structures, a means of nondestructive inspection (NDI) is necessary for both fabrication inspection and in-service damage. The traditional method of inspecting composites fabricated from tape prepreg has been through-transmission ultrasonics (TTU). In this method the attenuation of the acoustic signal is increased because of the presence of delaminations and porosity. Consequently, the quality of the structure can be determined via a rejection criteria based on signal attenuation. Textile composites introduce additional complexity to NDI. The presence of fiber architectures in which fiber orientation varies in the through-thickness direction can cause significant attenuation, and the attenuation in a defect-free part will vary with location. This behavior is caused by scattering of the ultrasonic signal by fibers of varying orientation. This causes the attenuation of the ultrasonic signal to be greatly increased, making it more difficult to detect delaminations or porosity.

5.1 INDUSTRY SURVEY

To gain an understanding of the state of the art in nondestructive examination of textile composites, an industry survey and a literature review (discussed in sect. 5.2) were initiated. The survey was conducted to determine: (1) current NDI methods for textile composites, (2) types of contamination and defects observed in textile composites, (3) methods for determining fiber volume fraction and void content, and (4) future needs in NDI technology for textile composites. Organizations surveyed are shown in table 5.0-1.

Aerojet
The Aerospace Corporation
Boeing Commercial Airplane Group
Boeing Defense & Space Group
Dow-UT Composites
Fiber Innovations
General Dynamics
McDonnell Douglas
U.S. Composites

Table 5.0-1. Organizations Participating in NDI Technology Survey.

5.1.1 Defects, Contamination, and Fiber Volume Fraction

Survey results showed that the types of defects typically found in textile composites included dry areas, improper ratios of resin, contamination of the preform with mold release agent, cross-contamination of fiber type from the braider, fiber pinching, and fiber wash. Foreign object contamination was not cited as a problem. The lack of foreign object contamination being cited is attributed to the respondent's perception that only RTM composites were being considered, and that the preforms were generated from the braiding or weaving process. In situations where preforms would also be fabricated from layers of dry fabric, then it is conceivable that foreign object contamination could occur in a shop floor environment.

Survey respondents indicated that acid digestion and cross sectioning of tag-end specimens were the accepted processes for determination of fiber volume fraction.

5.1.2 Current NDI Methods

A considerable difference in approach between prime aerospace contractors and small businesses in their approaches to NDI was noted. The prime contractors used ultrasonics, real-time X-ray, and film X-ray as standard NDI methods. The small businesses tended to use very little NDI. Small businesses stress process control and attention to detail.

5.1.3 Future Needs in NDI Technology

Several needs for development of NDI technology for textile composites were identified including:

- a. Inspection of hidden features of complex structures.
- b. Inspection of parts with complex curvatures.
- c. A desire to make NDI more quantitative.
- d. Detection of fiber wash.
- e. Detection and quantification of broken fibers.
- f. "Get away from standard C-scan techniques."
- g. In-process inspection.
- h. High-speed ultrasonic inspection.
- i. Quantification of porosity.

The common thread in inspection needs listed above is the cost of NDI. Parts must often be transported from the manufacturing facility to the inspection facility and then transported to an assembly area. Parts with complex curvatures or hidden features can not be inspected with standard equipment and so expensive computer controlled inspection systems must be used or inspection must be performed manually. Current ultrasonic inspection criteria do not give any indications of performance capability. Reject criteria are based on attenuation and the size and shape of the defect without regard to the type of defect. An improved NDI methodology would involve procedures closely linking the manufacturing site and would involve quantitative methods that would objectively evaluate structural performance.

5.2 NDI LITERATURE REVIEW

The literature review was initiated using the services of the Boeing Technical Libraries. The search resulted in a list of several hundred citations relevant to the study. A complete list of these citations are presented as a bibliography in Appendix B of this report. Initial review of the literature focused on porosity determination in textile composites. A review of some of the more significant papers in this area is also included.

The most significant body of literature on nondestructive examination of textile composites focuses on porosity determination. Hsu (ref. 1) evaluated the porosity volume in composites using the slope of the ultrasonic attenuation with respect to the frequency. This was performed using laminates fabricated from graphite/polyimide unidirectional tape as well as from woven graphite/polyimide. It was found that a linear relationship between porosity and ultrasonic attenuation existed for both tape and woven laminates. However, the constant of proportionality for each type of laminate differed. The difference was attributed to variations in pore morphology between woven and nonwoven composites. The nonwoven composites exhibit pores that are flatter and longer (i.e., more "needle like") in the interlaminar regions of the laminate. Such pores are very effective in blocking ultrasonic transmission. In woven laminates, however, the pores tend to localize in the resin-rich pockets of the laminate and remain relatively spherical. As a result, Hsu showed the attenuation and slope of the attenuation were lower by a factor of approximately two in the woven composite as compared to a tape composite having equal porosity. The relationship was tested on composites of different thicknesses as well as graphite/epoxy composites and was found to hold up relatively well.

The relationship between phase velocity and porosity was explored by Hsu in reference 2. Experiments were conducted on graphite/polyimide and graphite/epoxy material systems in both tape and woven form. Phase velocity measurements using broadband pulses were measured as a function of frequency. Porosity was found to cause a considerable decrease in ultrasonic velocity and a correlation was found to exist between void content and change in velocity. Additionally, the velocity dispersion was found to increase with increasing void content.

Analysis of ultrasonic backscatter for porosity characterization was explored by Roberts (refs. 3 and 4). The experiments were performed using azimuth-angle backscatter scanning in which a pulse-echo ultrasonic signal is transmitted at an incident angle to the composite of less than 90 deg. The specimen is then rotated about the z-axis and the reflected signal detected and analyzed. Backscatter scans were performed on specimens containing 0.01, 1.58, and 3.41 volume percent porosity, as measured by acid digestion. Distinct differences in the backscattered amplitude were observed for specimens of different porosity contents. Discrimination between porosity levels was better at 2.5 MHz than at 10MHz.

5.3 ULTRASONIC NDI OF TASK 5 AND TASK 7 PARTS

This section discusses the ultrasonic NDI that was performed on all parts produced in Tasks 5, 7.1 and 7.2 after completion of the RTM process. This was done to (1) determine the quality of molded panels, tubes, and angle sections; (2) provide feedback during the RTM process development in the early stages of the program; and (3) determine the ability of ultrasonic NDI techniques to detect defects in RTM parts made from textile preforms. The first two goals were achieved by inspecting all areas of all parts and ensuring that any areas of high attenuation were identified. Review of NDI results from parts that had unsatisfactory resin infiltration provided the necessary feedback to optimize injection pressures and location of venting ports. The third goal of determining the capabilities of existing NDI techniques to accurately find areas of porosity in textile panels was also met with the use of TTU and pulse-echo ultrasonic NDI. However, as all highly attenuated areas were removed from testing, a future program of testing defective areas would be extremely beneficial to understanding the effects of defects in textile composites.

All ultrasonic inspections were performed at the Boeing Quality Engineering NDI Laboratory. The primary responsibility of the NDI Laboratory is ultrasonic inspection of production composite hardware for programs such as the B-2, F-22, and 777. The size of composite hardware ultrasonically inspected in this lab range from small parts to structures as large as the 25 ft x 65 ft B-2 outboard wing section. Boeing's BAC 5980 specification entitled "Nondestruction Inspection of Composite Parts and Structures," is the baseline specification used during ultrasonic inspection of advanced composites. This spec controls the specific details of both pulse-echo and TTU ultrasonic inspection. It was very important to be able to compare panels of the same architecture that were scanned at different times. The use of BAC 5980 and the Gr/Ep standards defined within BAC 5980 provided the needed consistency. The following two types of ultrasonic inspection were used with the method selected determined by part shape:

Through-Transmission Ultrasonics (TTU) - All flat and curved panels underwent TTU ultrasonic inspection. TTU inspection method is defined as where ultrasonic energy is generated (transmitted) by one search unit and received by another at the opposite surface of the part. The TTU used for this program used a 1/4 in diameter water column and the water contained a small amount of wetting agent.

Pulse-Echo Ultrasonic - All tubes (braided and RTM'd at Fiber Innovations) underwent pulse-echo ultrasonic inspection. This technique is similar to TTU except that one search unit is used for both transmitting and receiving ultrasonic energy. As with the TTU method, a 1/4 in diameter water column was used and the water contained a small amount of wetting agent. The ends of each tube were sealed to prevent water from entering the tube and effecting acoustical reflection off the inner surface.

The pulse-echo method is much more sensitive to porosity because the sound goes through the part twice (along with a reflection loss off the back surface). Because of the highly attenuative nature of textile composites, the pulse-echo technique was judged to be too sensitive and the TTU method was used whenever possible.

Two types of C-Scans techniques (6 dB white out and full-size scans) proved to be the most successful at showing attenuation data in the RTM parts (C-scan is defined as a presentation method showing a 2D plan view of the scanned surface or part). Both C-scan techniques could be used for TTU and pulse-echo ultrasonic inspection. For archiving purposes, all data are electronically stored by part number.

6-dB White-Outs: This technique of showing attenuation proved to be best for showing data for a large quantity of inspected panels. The specific TTU facility used for this program was capable of scanning up to six - 24 in x 24 in panels at one time. Figure 5.3-1 shows 8 - 2D braid 11.5" x 24" panels and the reference standard. Using 6 dB increments, the first plot whites out all areas of attenuation ≥ 6 dB, the second plot whites out all areas of attenuation ≥ 12 dB, etc. This is repeated at 6-dB intervals until no whited out areas remain. As shown in figure 5.3-1, this technique permitted quick identification and location of areas possessing high levels of porosity. Foam pads were used to reference the panels to the C-scan. These pads showed up as very high levels of attenuation.

Full Size C-scan : As shown in figure 5.3-2, this style was used to detail panels that possessed marginal or unacceptable levels of porosity. Each larger number on the plot represents an increase of 6 dB. For example, the number 3 represents a range of 18 to 24 dB and 4 represents a range of 24 to 30 dB. Also, as numbers increase in value, the contrast is increased to assist in identification of areas containing high levels of porosity. The full-size capabilities facilitated the identification and marking of areas of high attenuation on individual panels.

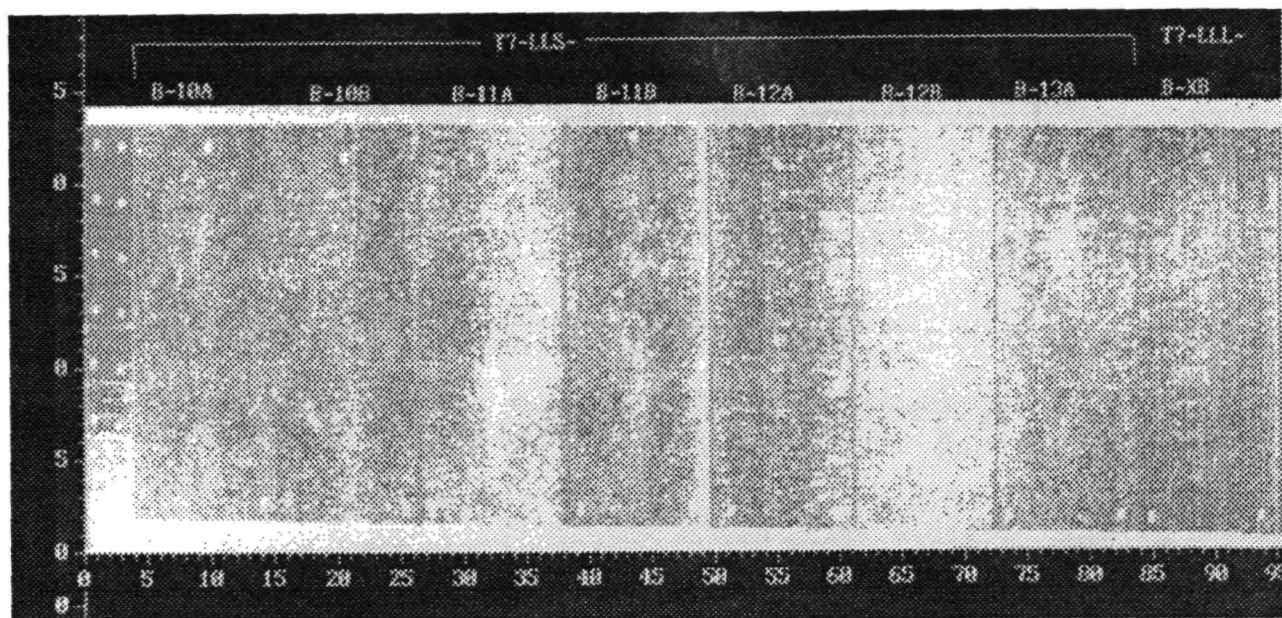
All dB values are the attenuation difference between the molded part and a reference standard. These standards are used to adjust NDI equipment sensitivity and/or resolution and may contain known defects. As no textile standards exist at Boeing, equivalent thickness graphite/epoxy (Gr/Ep) standards were used. For example, a 0.230-in-thick Gr/Ep standard was used for 0.25 in thick panels. 5 MHz was used throughout this program as the effective peak ultrasonic wave frequency. Increases in attenuation identify areas of porosity. This porosity is a result of defects such as delamination (delamination is not possible in the 3D interlock woven panels), voids, inclusions, or microcracking. In most cases, destructive inspection is required to determine the exact cause of increasing attenuation. No inclusions were found in any of the parts. 3-3.

Table 5.3-2 shows attenuation acceptance criteria for porosity versus part thickness for Gr/Ep composite parts. This table is shown to illustrate how acceptable attenuation levels increase for thicker Gr/Ep parts. (This table is shown only as an example of how one program's acceptable attenuation increases with thickness for Gr/Ep parts. It was not used on this textile composite program.) Parts thicker than 0.441 in require the use of 1 MHz or 2.25 MHz frequencies. Because textiles are a relatively new material, no acceptance criteria was used on this program.

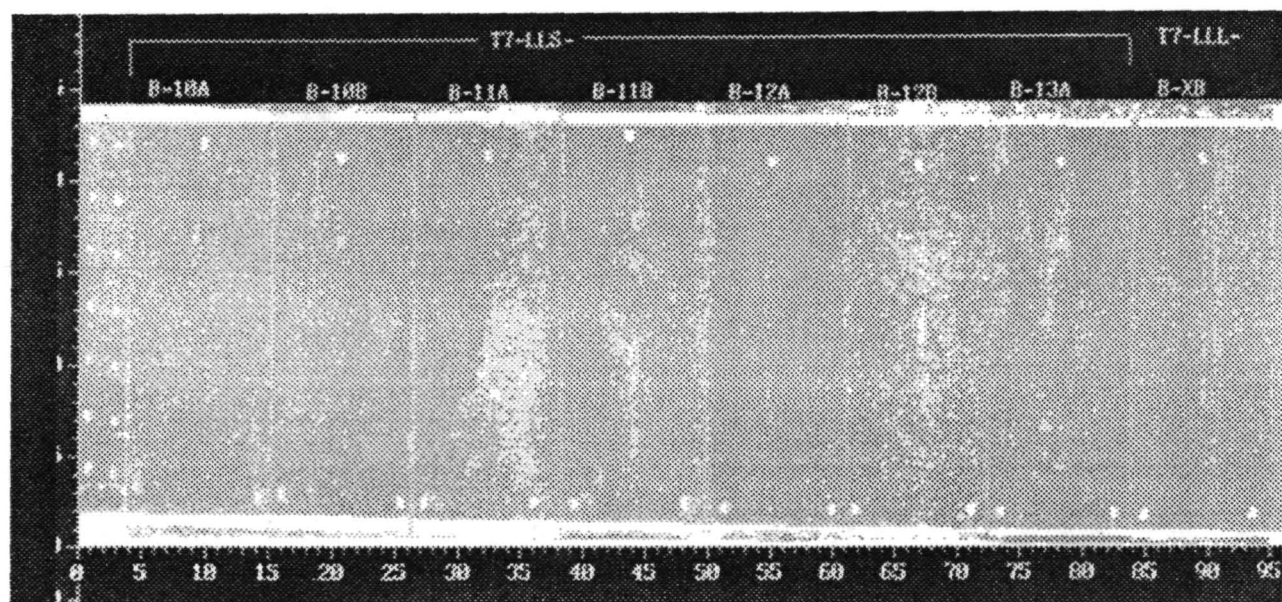
Part Thickness, inch	Acceptable Attenuation, dB
0.045 - 0.120	8
0.121 - 0.200	12
0.201 - 0.280	18
0.281 - 0.360	29
0.361 - 0.440	40
> 0.441	NA

Table 5.3-2. Attenuation Criteria for Porosity in Gr/Ep

Following completion of the RTM process, all parts underwent ultrasonic inspection at Boeing. This included the 2D braided tubes and curved panels molded at Fiber Innovations. The following sections summarize the results for each shape and architecture.

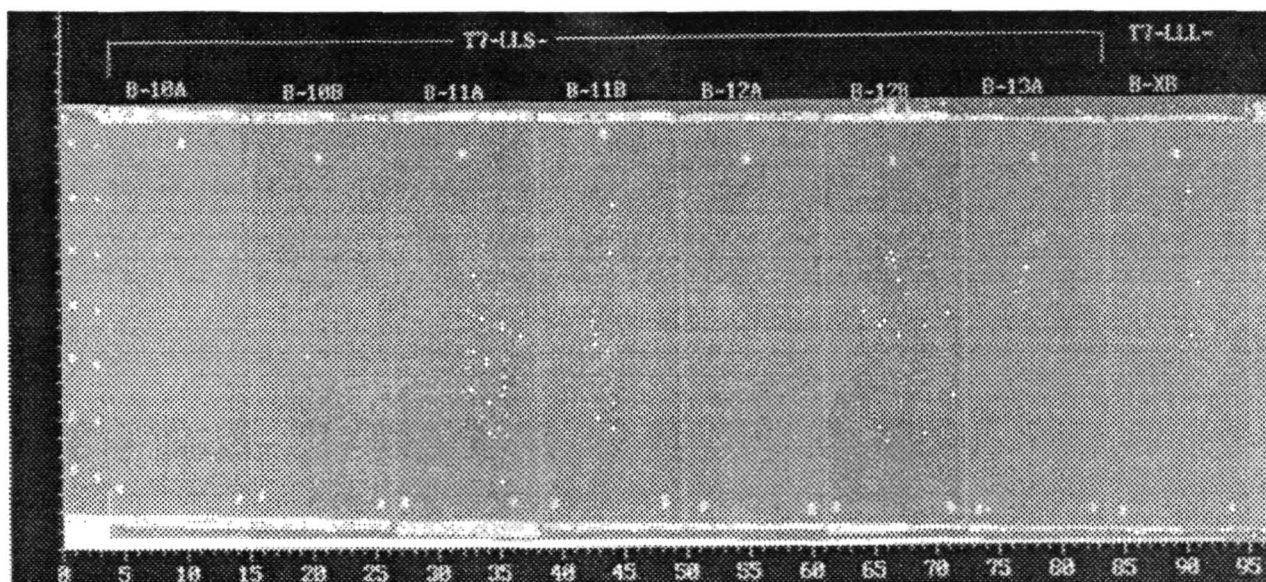


6 dB White-Out

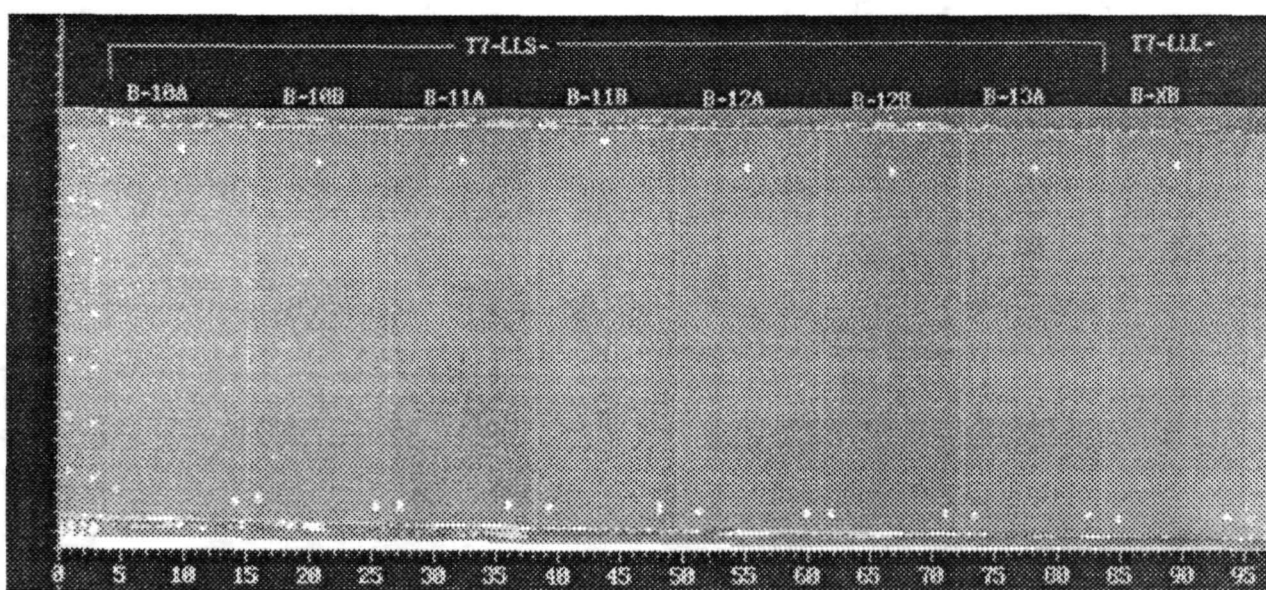


12 dB White-Out

Figure 5.3-1. 6 dB White-Out of 8 2D Braided Panels



18 dB White-Out



24 dB White-Out

Figure 5.3-1. 6 dB White-Out of 8 2D Braided Panels (Cont)

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Page 1 of 1

Character Definition Table				
Symbol	dB Voltage	Minimum Intensity	Maximum Intensity	dB Voltage
blank	6	6.95V	174	48
1	-6	6.28V	155	6
2	-12	5.77V	144	-6
3	-18	5.34V	133	-12
4	-24	4.91V	122	-18
5	-30	4.49V	112	-24
6	-36	4.06V	101	-30
7	-42	3.63V	90	-36
8	-48	3.20V	79	-42
9	-54	2.77V	69	-48
0	-60	2.34V	58	-54
#	-66	1.91V	47	-60
solid	-91	0.88V	1	-66

There are 6 dB, 0.43 volts, and 10.7 intensity per plot symbol

File Name: 2C788
Part Name: SEE REMARKS
Serial Number: N/A
Reject Tag Number: 07/17/92
Scan Date: 08/01/92
Scan Time: 10:18
Max Contrast (Mean): 164

Print Region: 1.5, 26.9 to 14.6, 0.1
Comments:
Index Increment (Y): 0.000
Scan Increment (X): 0.000
Operator: R.J.S

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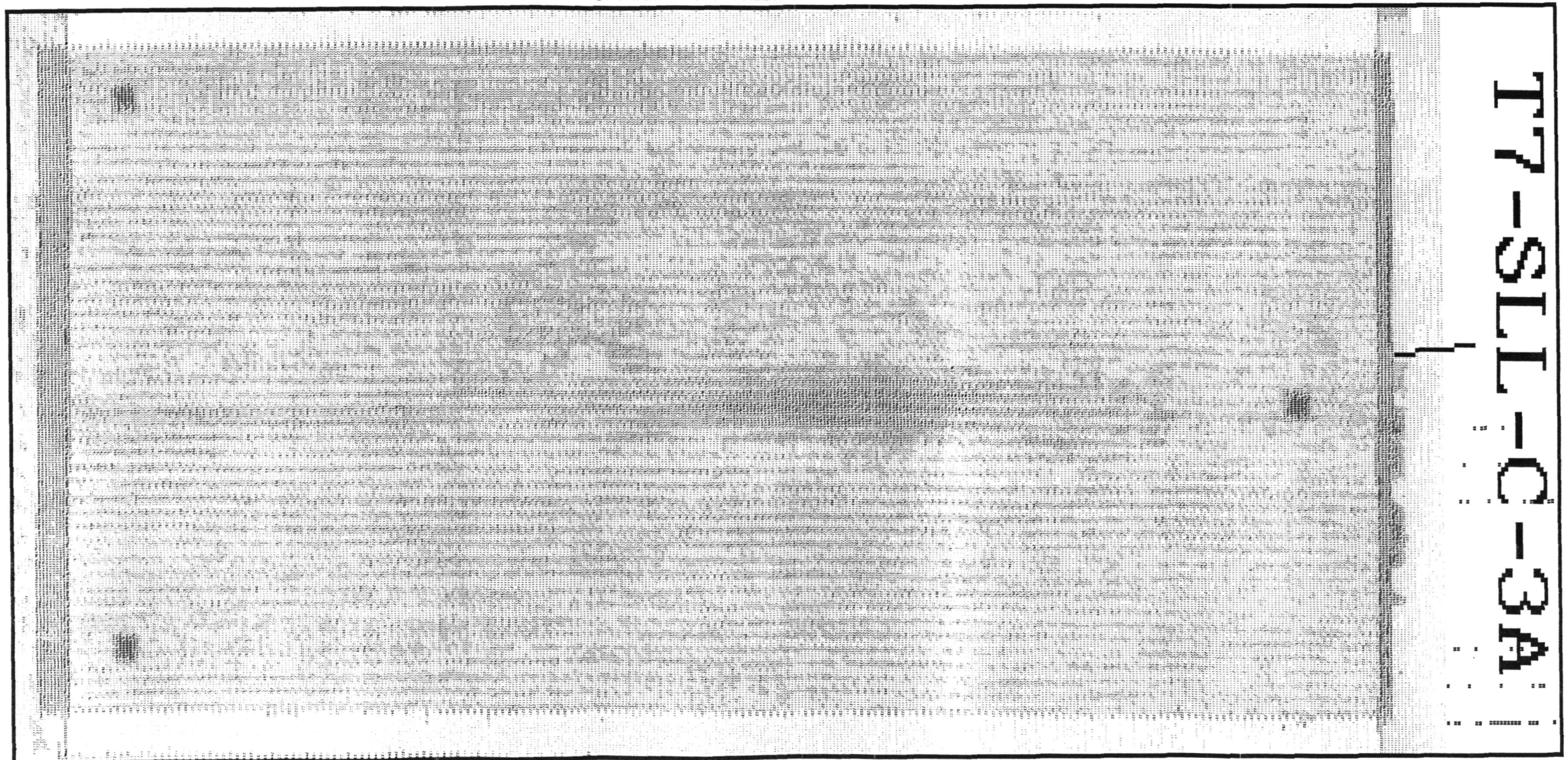


Figure 5.3-2. C-Scan of an 11 1/2 in x
24 in SLL 2D Braid Panel

FOLDOUT FRAME

FOLDOUT FRAME

5.3.1 2D Braided Flat Panels

Figure 5.3.1-1 shows a 18-dB white-out for 36 of the 1.5-in x 24-in 2D braid panels. Greater than 18 dB attenuation can be seen in several of the panels including three of the four LLL panels. Foam pads, with the resulting high attenuation, were placed on the bottom of each panel in order to reference each panel to the C-scan.

Figure 5.3.1-2 shows the variation in background attenuation for the three of the four 2D braid architectures. All four of the 1/4 in thick panels were of excellent quality with no localized areas of porosity. The two LLS panels had very little attenuation greater than 12 dB while both the LLL and LLS panels, which were of equal quality, showed areas of attenuation greater than 18 dB.

5.3.2 2D Braided Tubes

Fiber Innovations was subcontracted to supply the RTM tubes. Upon delivery to Boeing, all tubes underwent pulse-echo ultrasonic inspection.

To keep the ultrasonic transducer perpendicular to the tube, a Teflon shoe was machined for each of the three diameters and the transducer placed in the shoe during the automated scanning. Unlike the flat panels, which remained stationary during the testing, the tubes were incrementally rotated under a transducer that traveled along the length of the tube. Figures 5.3.2-1 through 5.3.2-4 show typical results from scanning of the four different 2D architectures. These figures show the subtle differences in background attenuation for each of the four architectures. In all four cases, the nickel-coated tracer yarns can be seen. During scanning the tube is rotated past the initial starting point so that the foam pads seen on the top of the C-scan are the same ones shown on the bottom of the C-scan.

Four of the five 3.803 in OD LLL tubes possessed localized areas of porosity. Figure 5.3.2-4 shows a typical area of porosity in the lower left-hand corner. This figure also illustrates the repeatability of ultrasonic NDI. Note that the same porosity shows up again in the upper left-hand corner of the C-scan as the tube is rolled past its starting point during scanning. Two 30 in long horizontal lines, best shown in figure 5.3.2-1, are from the minor pinching of material on the exterior surface. This was caused by the exterior mold being made in three pieces and pinching the tube during closing of the mold.

All tubes were molded at Fiber Innovations, shipped to Boeing for NDI and then shipped to either Penn State University (Dr. David Jenson) or University of Utah (Dr. Steve Swanson) for mechanical testing. Unlike the flat panels where areas of high attenuation could be removed from future testing, areas of high attenuation were identified on the tube and then the whole tube tested. This allowed an opportunity to determine the effect of porosity on mechanical properties. Future activities, to be performed at the two universities, will compare the location and type of failure to the pre-testing NDI results.

5.3.3 2D Braided Angles

Fiber Innovations was also subcontracted to provide the 14 1/8-in-thick 2D braided angle panels. The braided preforms used to make the angle panels were only border stitched along one side. This allowed the individual layers of the flat preform to conform to the radius with minimal, if any, damage to individual fibers. Because the angle panels will be tested to determine their out-of-plane properties, the radius is the area of most interest. Due to the tight radius and the need to keep the transducer perpendicular to the area of interest, a hand-held transducer was used. The most effective way to determine the quality of an angle panel was to first inspect the flange areas with the standard automated TTU equipment. This established the "standard" for that particular panel and architecture. Using the hand-held transducer, the radius was then inspected and results compared to the flange areas. The results of TTU inspection showed that all 2D braided angles were of good to excellent quality. Typical attenuation ranges for an entire 2D braid angle panel, including the radius, was 3 to 18 dB.

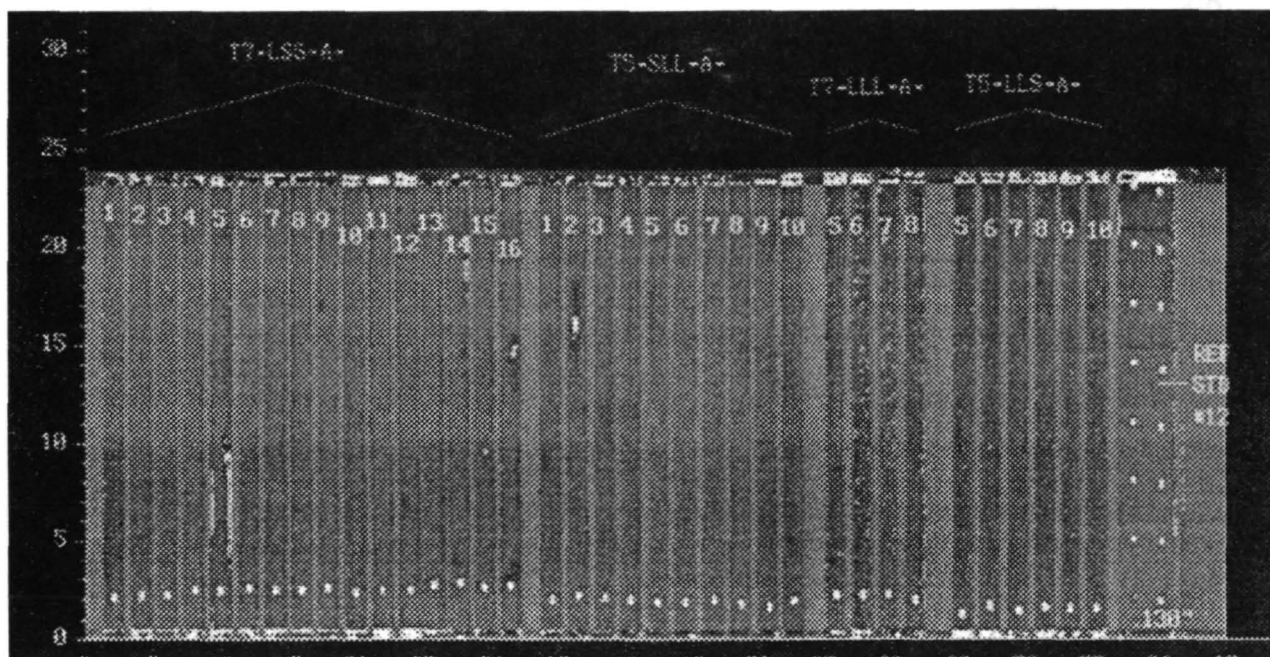
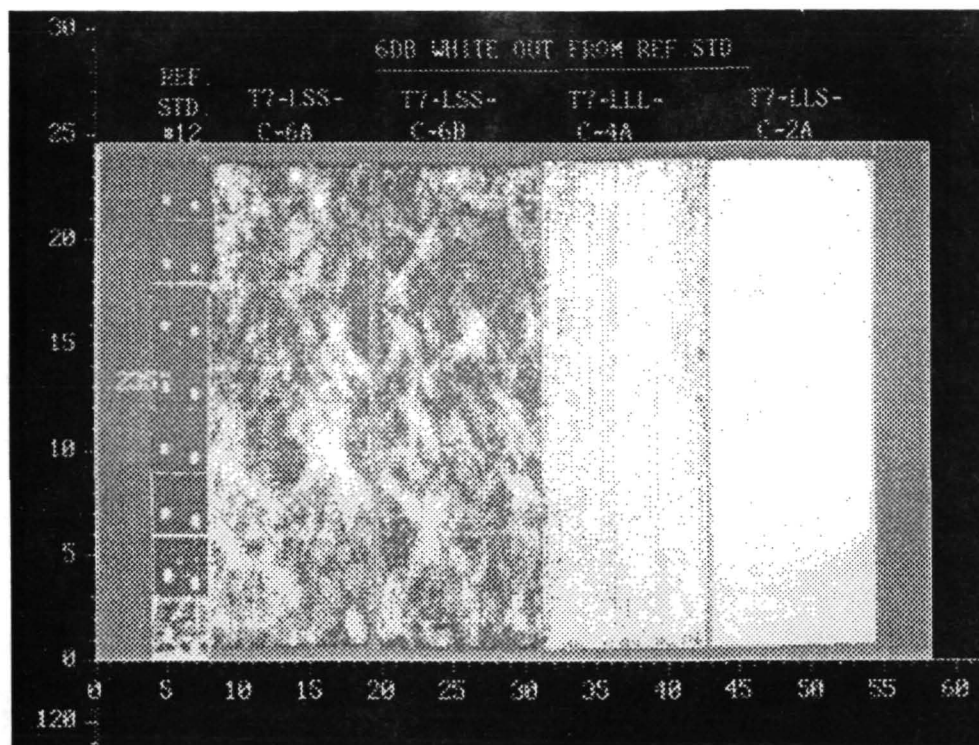
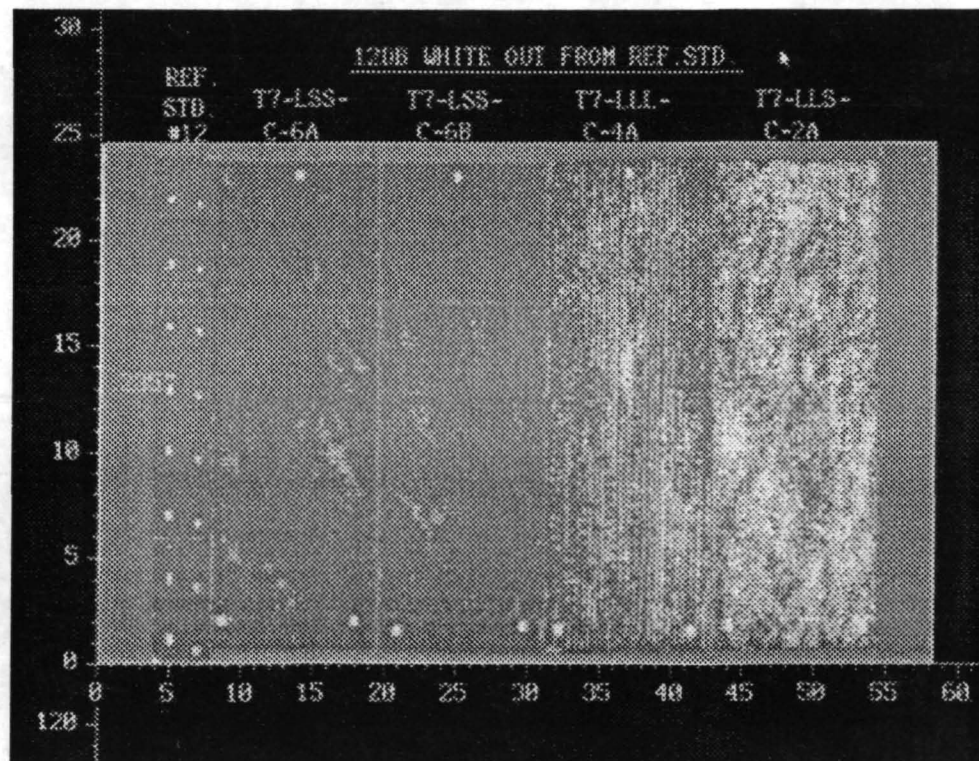


Figure 5.3.1-1. 18 dB White-Out of 36 1.5"x24"
2D Braid Panels

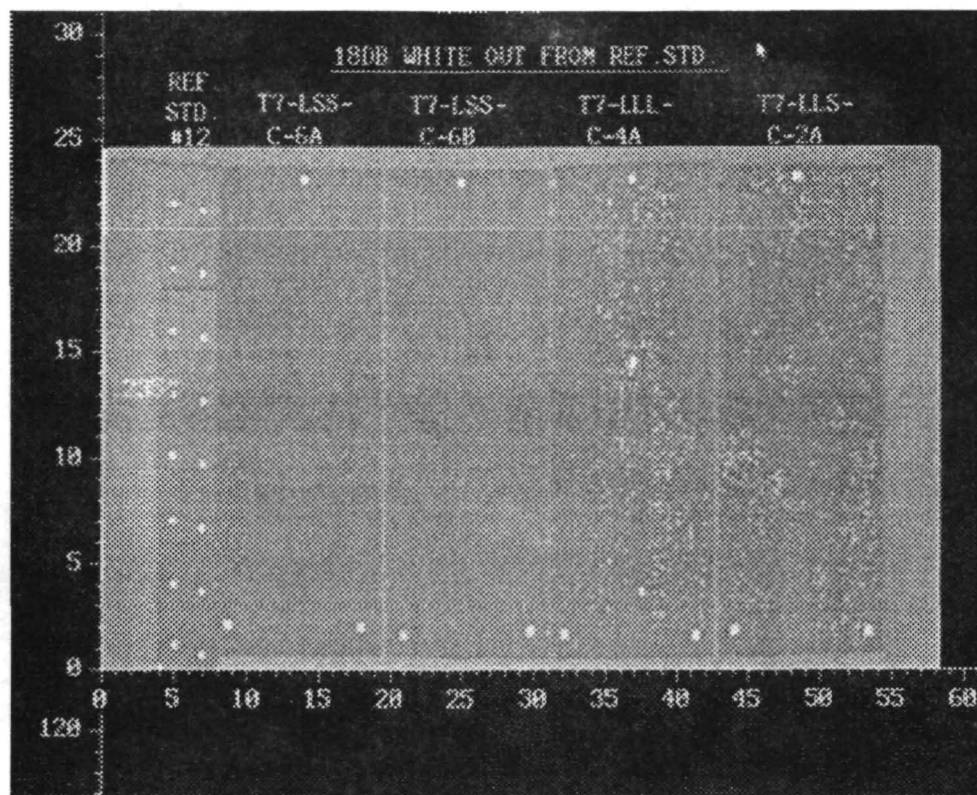


6 dB White-Out

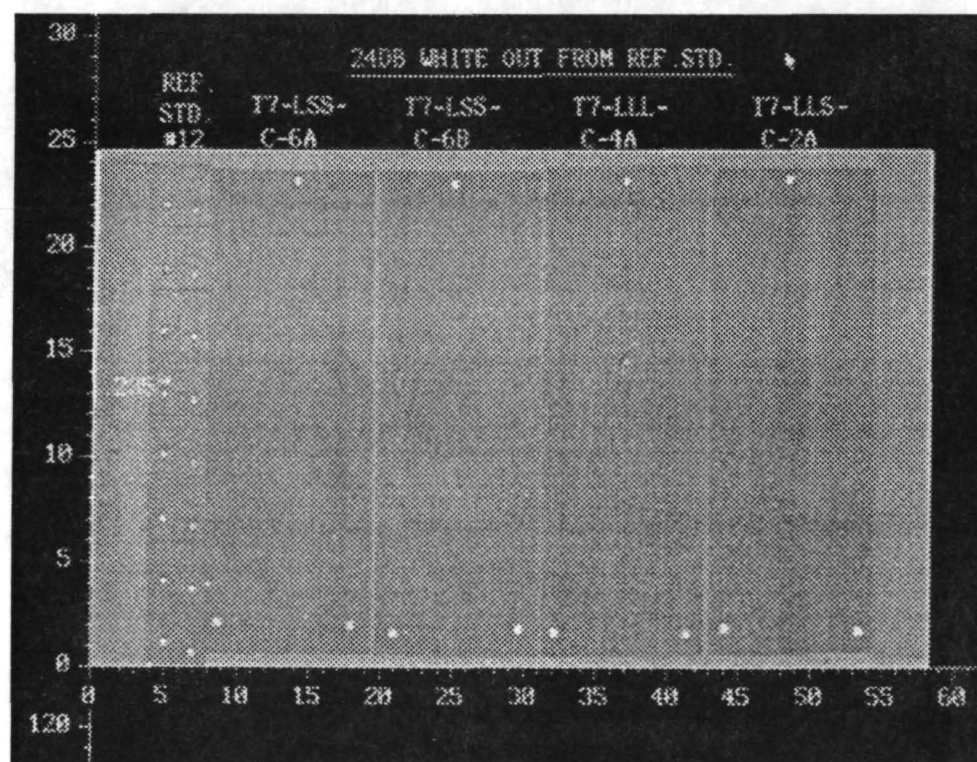


12 dB White-Out

Figure 5.3.1-2. 6 dB White-Out of 3 LSS, LLL, and LLS 2D Braid Panels



18 dB White-Out



24 dB White-Out

Figure 5.3.1-2. 6 dB White-Out of LSS, LLL, and LLS 2D Braid Panels (Cont)

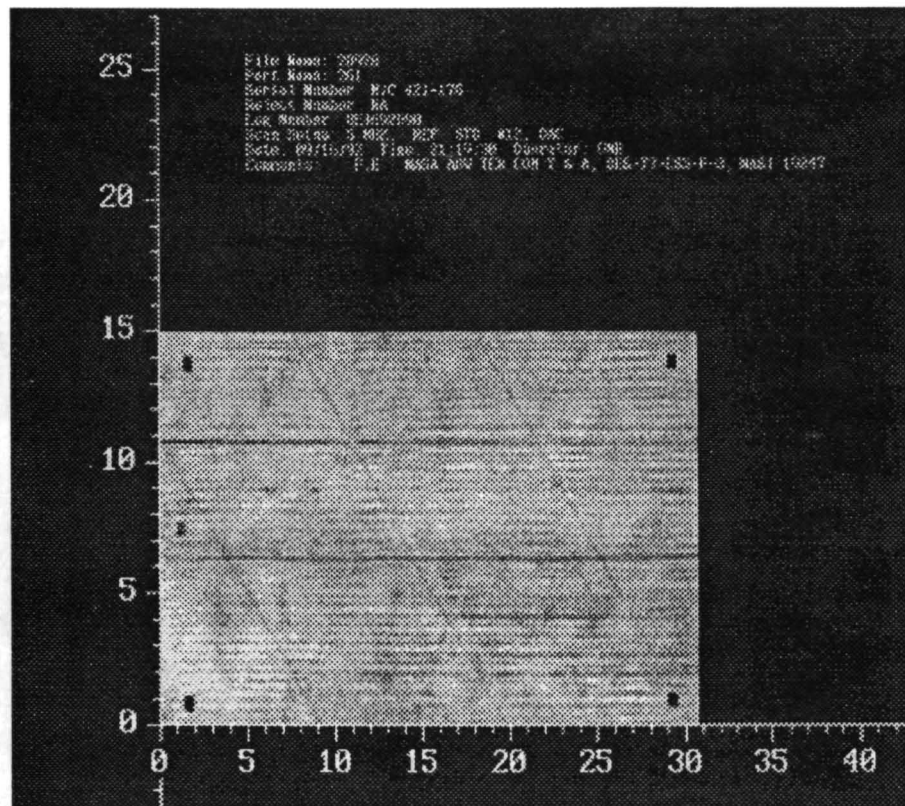


Figure 5.3.2-1. C-Scan of 3.8" Diameter
LSS 2D Braid Tube

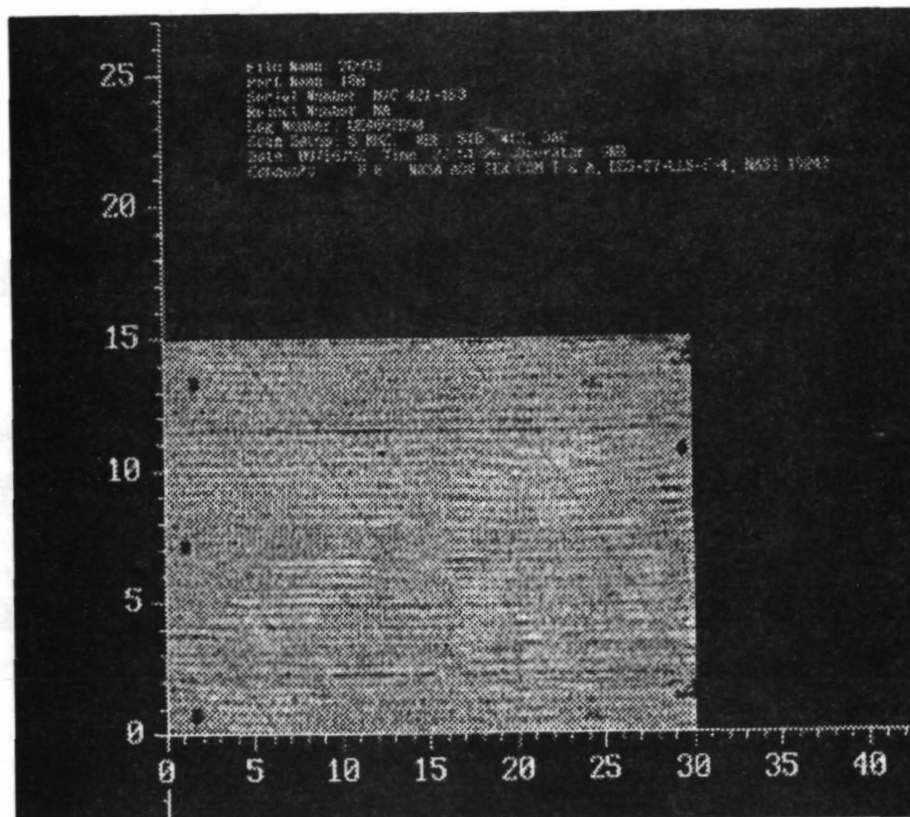


Figure 5.3.2-2. C-Scan of 3.8" Diameter
LSS 2D Braid Tube

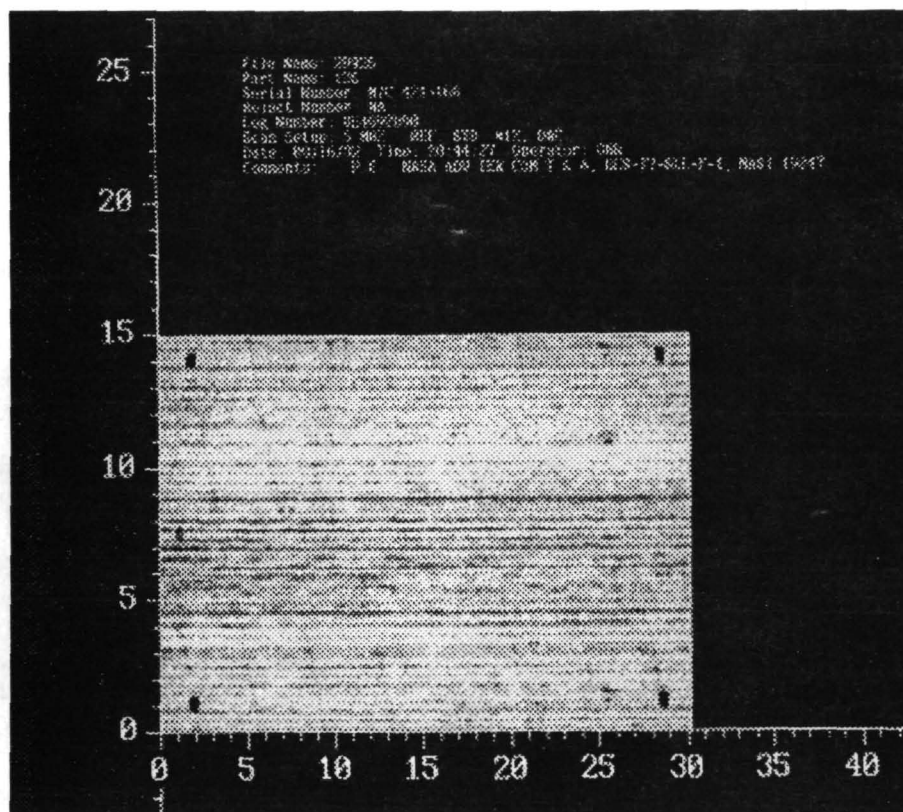


Figure 5.3.2-3. C-Scan of 3.8" Diameter
SLL 2D Braid Tube

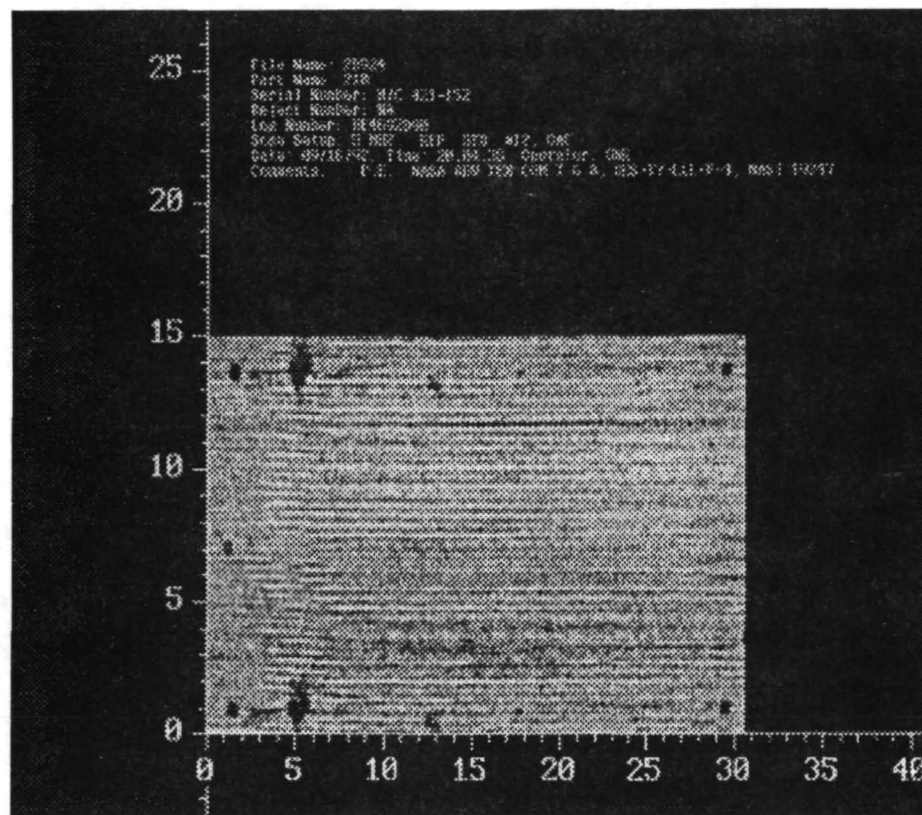


Figure 5.3.2-4. C-Scan of 4.8" Diameter
 LLL 2D Braid Tube

5.3.4 3D Interlock Woven Flat Panels

A total of 36 11.5-in x 24-in interlock woven panels and an additional 10 5-in x 24-in LS-1 panels were molded and TTU'd at Boeing. Because of the variety of the through-thickness fiber orientations and fiber tow sizes, the background attenuation for the six different interlock woven panels varied from architecture to architecture. This is shown in figure 5.3.4-1 which is a series of 6 dB white-outs for two OS-1 and two OS-2 panels. Both OS-1 panels showed an attenuation range of 6 to 18 dB while equal good-quality OS-2 panels possessed attenuation in excess of 42 dB. To verify that the high attenuation loss of the OS-2 panels was not a result of porosity, the void volume of the T7-OS1-A-1A and T7-OS2-A-1B panels were determined by measuring the density of each panel. The OS-1 panel had 0.5% porosity while the OS-2 panel had 0.3% porosity, showing that both panels were of good quality.

Figure 5.3.4-2 shows a series of 6-dB white-outs for eight 5-in wide LS-1 panels. These panels were all of good quality.

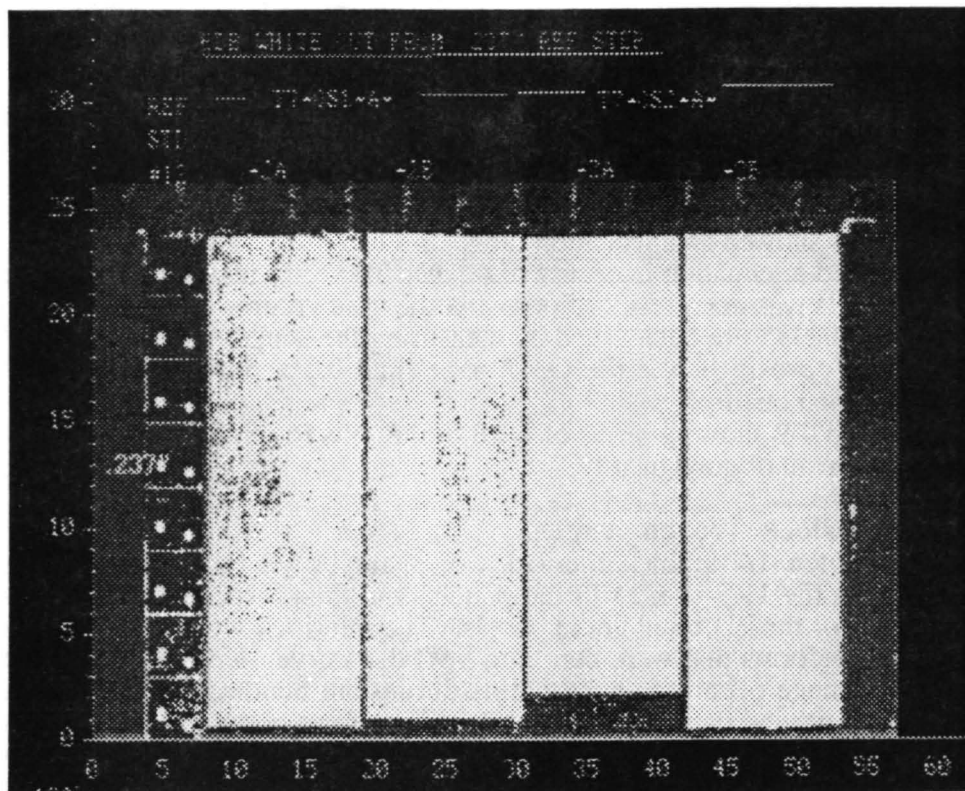
5.3.5 3D Interlock Woven Angles

A total of ten 1/4-in thick interlock woven angles were molded (using the preform material used for the 11.5-in x 24-in flat panels) and then inspected using the same NDI technique used for the 2D braid angle panels. The interlock woven angles were molded from flat, stiff preforms that were bent into a 90-deg curve. Unlike the 2D braid curved panels, fiber damage occurred at the radius during the bending of the interlock woven preforms and additional damage occurred during preform compaction. For example, the attenuation loss through the flange portions of LS-2 and OS-1 curved panels was ≈ 12 dB. The attenuation loss through the radius portion was an additional 30 dB. This increase in attenuation was caused by (1) fiber damage and (2) reflection of the signal caused by the difficulty of holding the transducer normal to the radius, combined with the small radius.

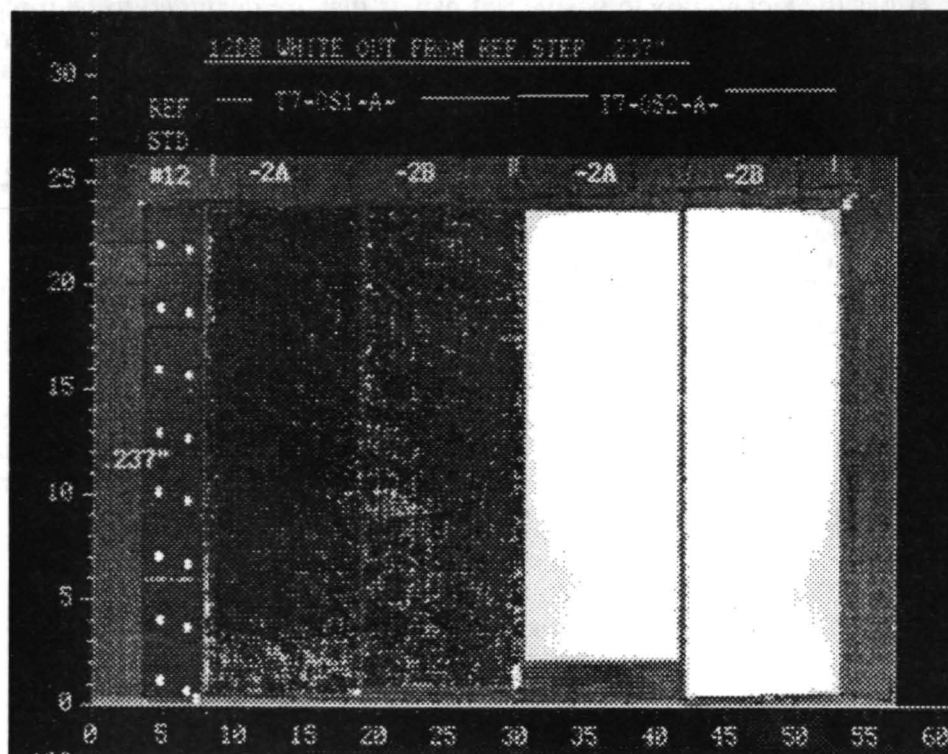
TTI has the technology to weave flat panels that are designed to be molded into a curved shape. The completed woven preform is flat and folded, with one side of the fold having excess yarn and the other side having tightened yarn. The preform can then be opened and molded with minimal damage to the fibers at the radius. Future efforts should include a comparative testing program to determine whether the angle panels molded from these preforms possess better mechanical properties than flat interlock woven preforms bent into a 90-deg curve.

5.3.6 Stitched Uniweave Panels

Up to six 24-in x 24-in stitched uniweave panels (SUW) were TTU'd at the same time. All 10 stitched uniweave panels were of excellent quality with minimal attenuation beyond 18 dB, as shown in figure 5.3.6-1. This figure shows that localized porosity in excess of 18 dB existed near the center in four of the panels. This porosity was caused by the four resin flow fronts not meeting exactly at the venting port, which is located at the center of the mold. This caused a small area of poor resin infiltration near the center of the four panels. These areas were marked on the panels to ensure that the test specimens were not cut from areas with poor resin infiltration.



6 dB White-Out



12 dB White-Out

Figure 5.3.4-1. 6 dB White-Out for 2 OS1 and 2 OS2 Interlock Woven Panels

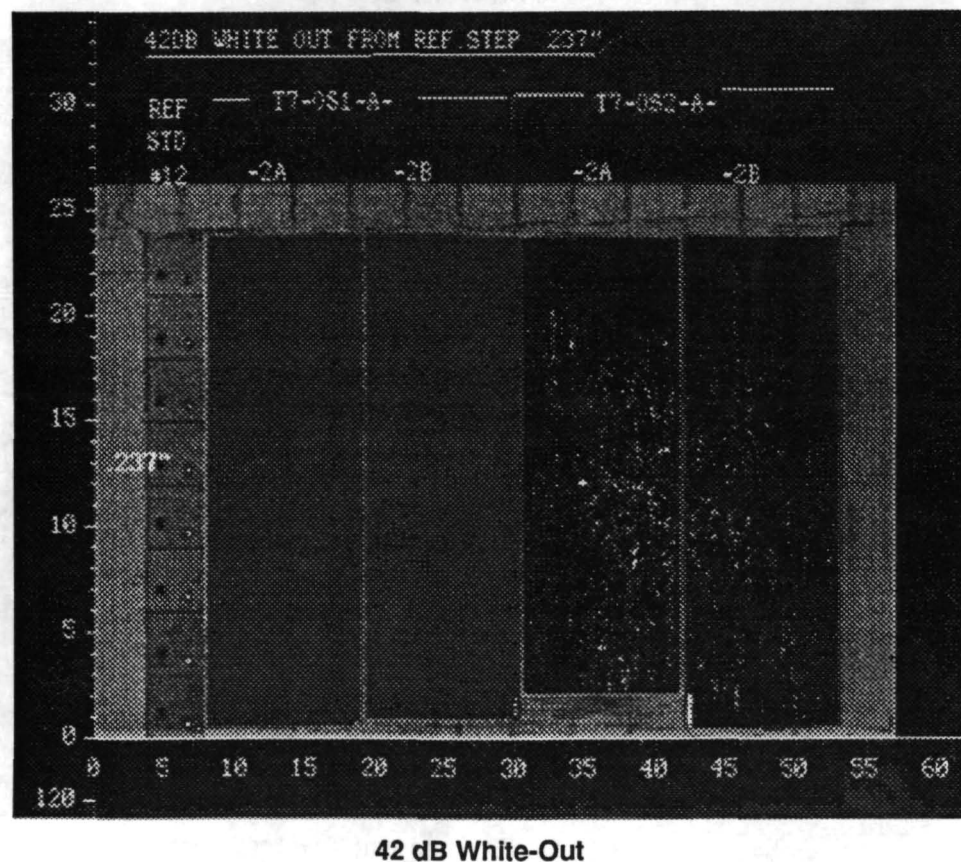
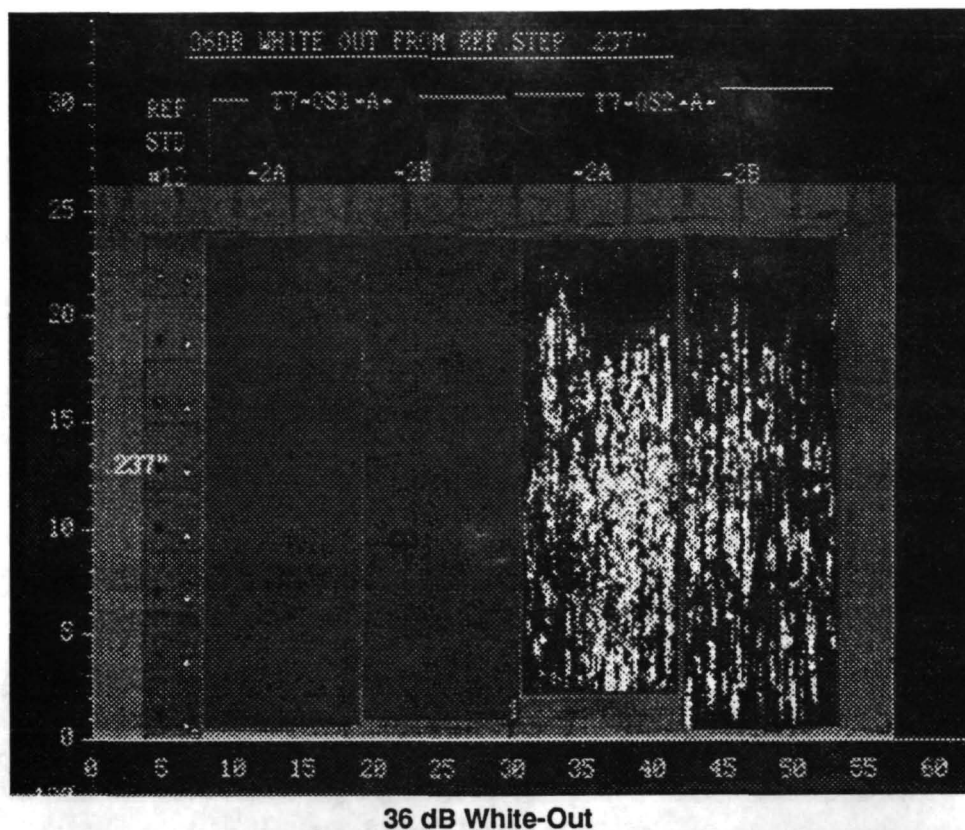
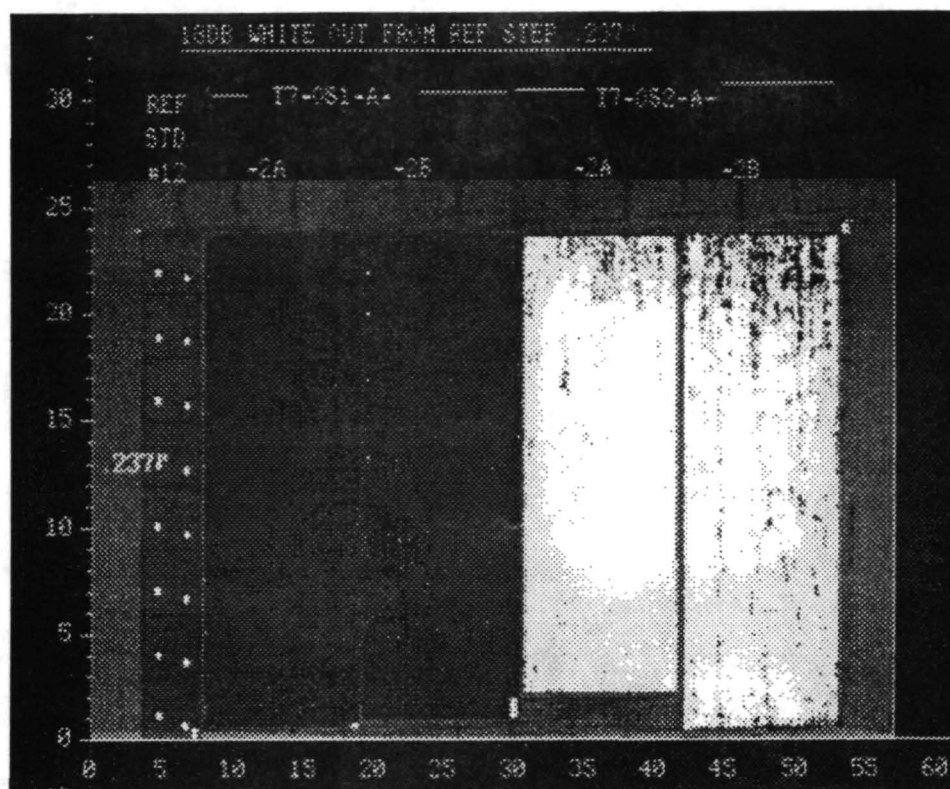
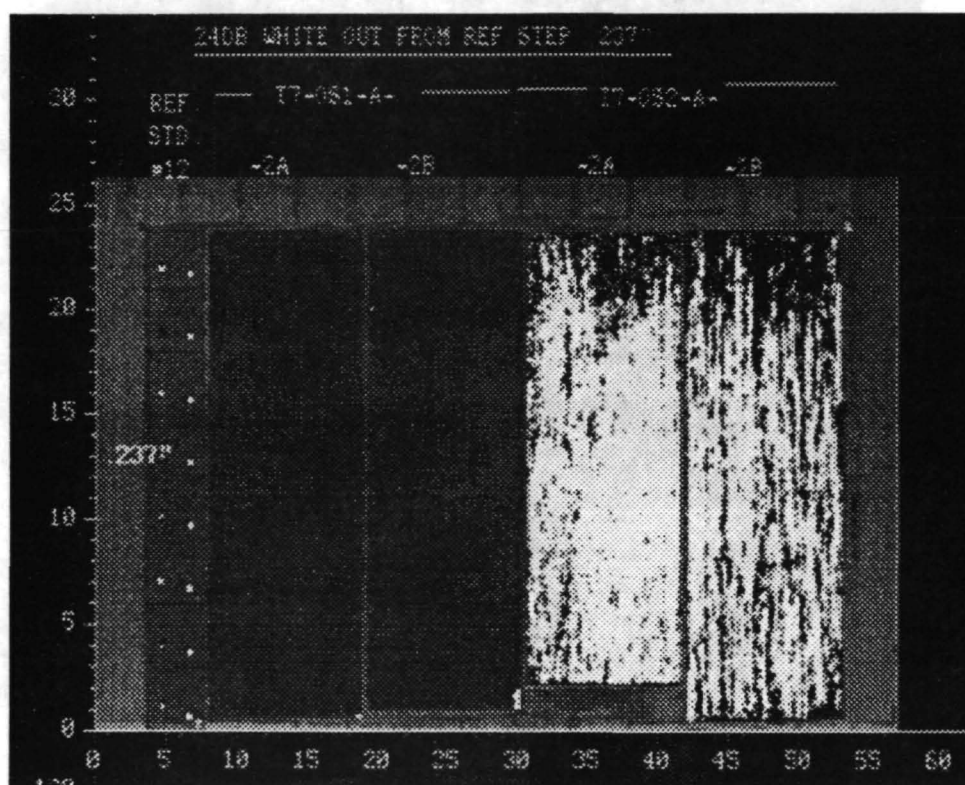


Figure 5.3.4-1. 6 dB White-Out for 2 OS1 and 2 OS2 Interlock Woven Panels (Cont)

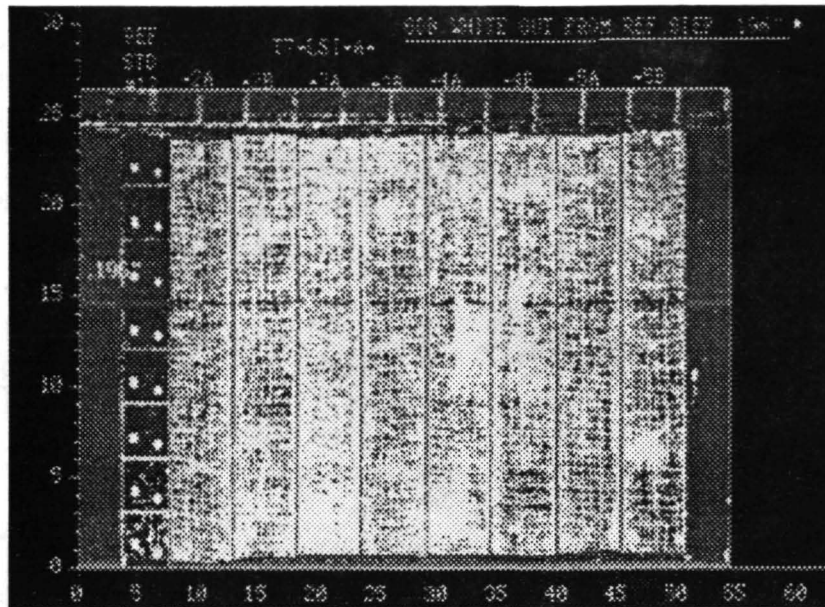


18 dB White-Out

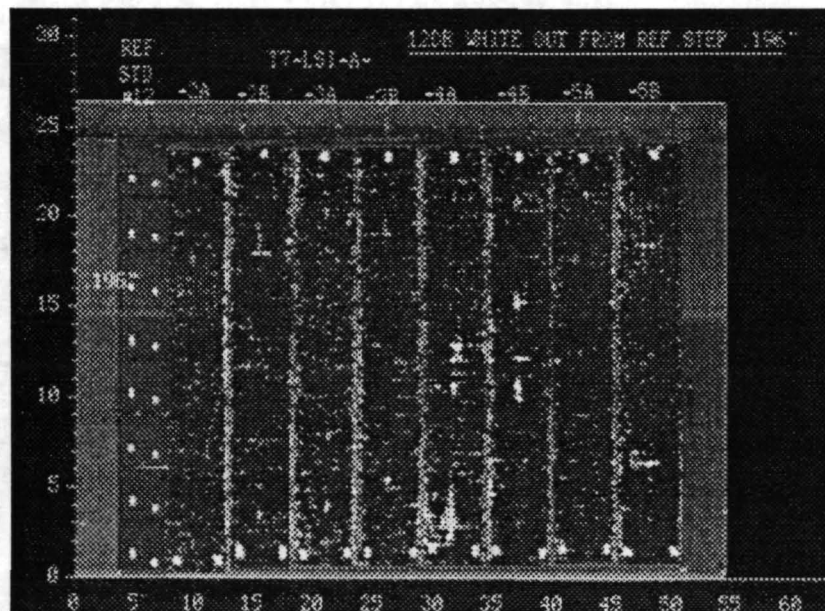


24 dB White-Out

Figure 5.3.4-1. 6 dB White-Out for 2 OS1 and 2 OS2 Interlock Woven Panels (Cont)

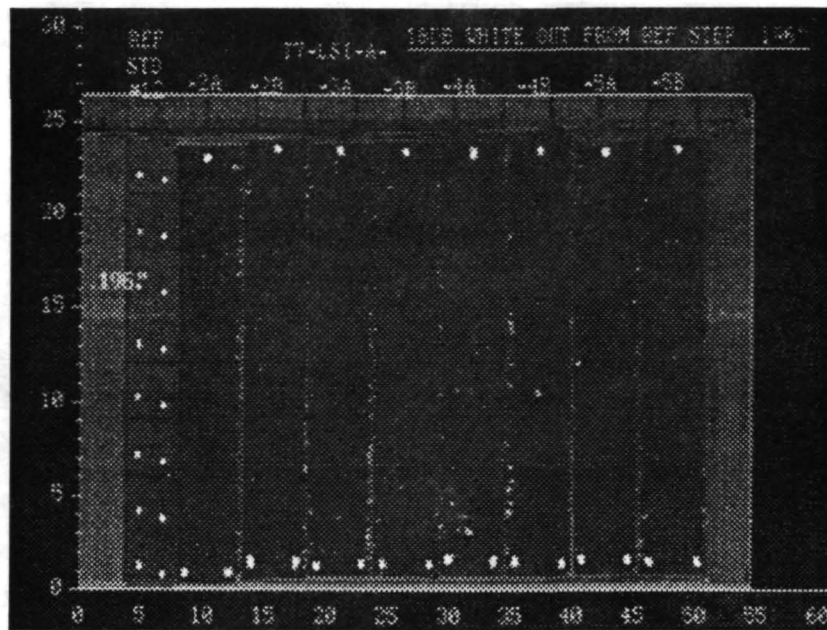


6 dB White-Out

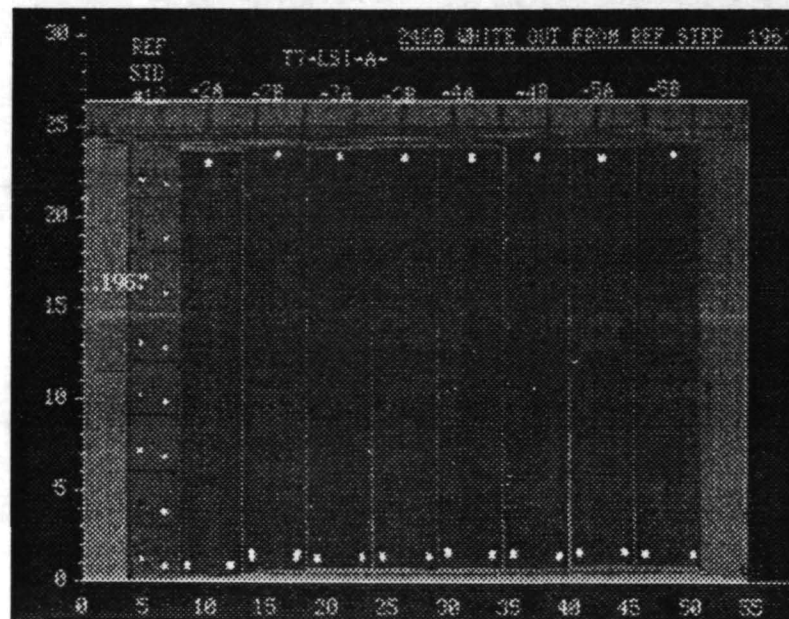


12 dB White-Out

Figure 5.3.4-2. 6 dB White-Out of 8 5"x23.5"
LS-1 Interlock Woven Panels



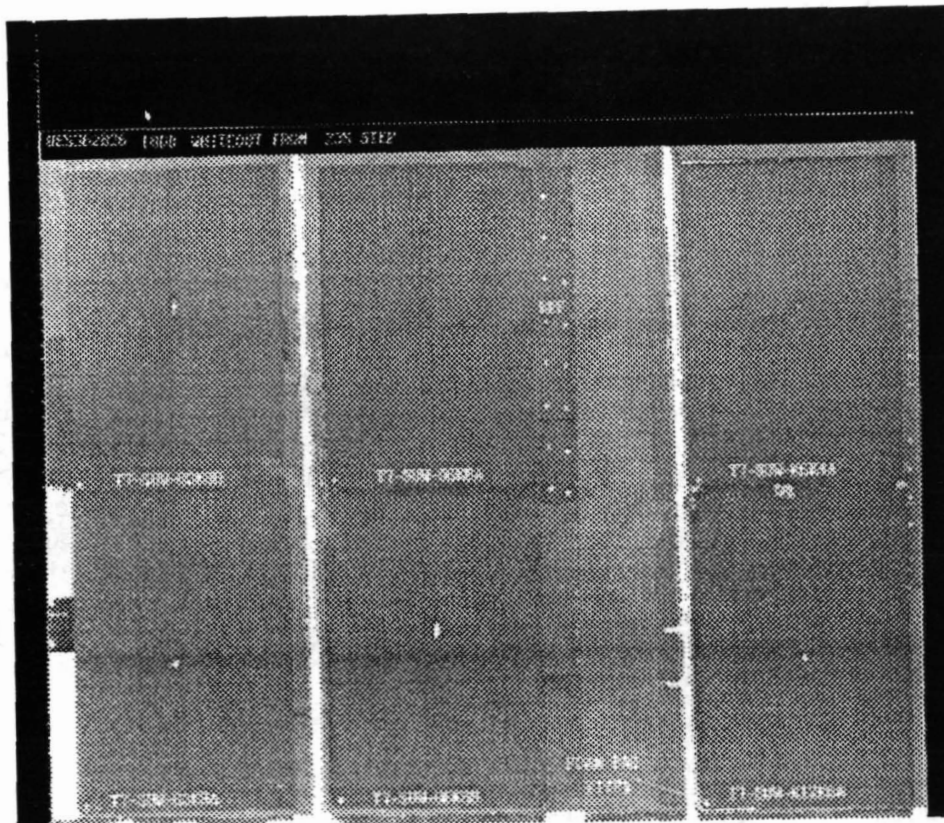
18 dB White-Out



24 dB White-Out

Figure 5.3.4-2. 6 dB White-Out of 8 5"x2
LS-1 Interlock Woven Panel (Cont)

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*Figure 5.3.6-1. 18 dB White - Out of 6 - 24"x24"
Stitched Universal Panels*

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6.0 CONCLUSIONS

Material Selection:

Four categories of preform architectures were investigated in this program: stitched uniweave, 2D-braided, 3D-braided, and interlock woven. All braided preforms were of good quality. Interlock woven fabric is a three dimensional fabric in which yarns are woven through the thickness to provide greater resistance to delamination (greater toughness) than conventional laminates. The quality of Textile Technology's interlock woven preforms ranged from acceptable to possessing architectural defects. The poor-quality preforms were identified by either Textile Technology or during pre-RTM inspection at Boeing. We have concluded that a need exists for improved nondestructive capabilities in identifying and confirming fabric architectures prior to molding. Shell's RSL-1895 epoxy resin with the Epon Curing Agent W was found to be easy to process. The resin has a low viscosity at processing temperature, and is relatively insensitive to autoheating (uncontrolled exotherm). However, as with many uncured epoxies, the toxicity of the heated resin requires special handling procedures.

Processing:

The picture-frame mold design proved successful in the RTM of many sizes and shapes of parts. The technique of injecting resin from the perimeter of the preform and venting from the center also proved successful. This technique permits variation in preform length and width, and completely eliminates the resin blow-by problem. The same injection/venting concept worked in the fabrication of the 90 deg. curved panels. Most of the 12 in by 24 in laminates were molded four at a time in a dual cavity (side-by-side, top-and-bottom) configuration. The net-shape braided preforms, 1.5 in by 24 in, were fabricated 12 at a time in the same mold using a specialized insert. This demonstrated the feasibility and economics of fabricating multiple parts at a time. The repair of a poorly infiltrated panel was completed by inserting the part back into the mold and reinfiltrating resin into the dry areas. The repair concepts for resin transfer molded textile composites may follow similar ideas. It may be possible to repair impact damage, characterized by minimal fiber breakage, by dissolving the damaged resin with an acid wash, followed by resin infiltration between parallel plates.

Photomicroscopy and Microcracking:

Microcracking occurs predominantly in the interlock woven architectures. And, of the six interlock woven architectures, microcracking occurs most often in the orthogonal interlock materials, OS-1 and OS-2. Microcracking is caused by the chemical shrinkage of the polymerization process, the fiber/matrix thermal contraction mismatch during cool-down, and constraints on resin shrinkage by the fabric architecture during cure. We were able to reduce the amount of microcracking by using a lower temperature (250°F), extended-time cure cycle. 3M's PR-500 and British Petroleum's E905L resin system microcracked to the same extent as Shell's RSL-1895 with the extended cure cycle. Microcracking in the orthogonal interlock panels could not be eliminated, given our current set of materials. Shell's RSL-1895 resin and the extended cure cycle was used in the fabrication of all subsequent interlock woven and stitched uniweave panels (including the 3D braided-panels). It was not necessary to use the extended cure cycle in the 2D braided flat panels architectures because microcracking was not prevalent in these panels. However, a moderate amount of microcracking occurred in the LLL tubes so an extended cure cycle (270°F cure) was used to fabricate all deliverable LLL tubes.

NDI Industry Survey and Literature Search:

The use of textile composites in aircraft structure is not mature enough to bring visibility to NDI technical issues. Current usage of textile composites in structure is most common in secondary structure where strength is not a design driver. Secondary structure usage is mostly found in sandwich structure, in radomes, and in fairings. Fairings must withstand foreign object damage but generally just act as an aerodynamic surfaces. Commonly the inspection requirement for such structures is to determine if (1) a skin is adequately bonded to the core and (2) porosity of the skin.

Review of the literature indicates that there is poor communication between industry and academia investigating NDI technology. It doesn't appear that academia is working the problems industry has identified.

Ultrasonic NDI:

Ultrasonic scanning is a highly automated process and, with the exception of having to manually move the transducer when scanning the radius of the angle panels, proved to be an easy and cost effective way to NDI molded textile composites. The scanning allowed us to eliminate areas of high attenuation from inclusion in the mechanical test program. Although there was no acceptance or rejection criteria established in the SOW, the ultrasonic C-scans, in combination with visual inspection, proved to be a highly effective means of judging the quality and identifying specific areas of porosity of the panels following completion of the RTM process.

The scanning of the radius portion of the curved panels was the only area in which operator expertise was required. Due to the use of the hand-held transducer, this scanning process proved to be the only time when consistency was difficult to achieve.

The absence of textile standards of the same thickness and architecture as that of the parts undergoing NDI added to the difficulty in interpreting NDI results. We had to ultrasonically inspect several panels of a specific architecture to determine the background attenuation for that specific architecture. It is proposed that once a specific architecture has been selected for further development, the fabrication of a textile standard of that architecture be included. Because each architecture had its own baseline attenuation, this would assist in determining the quality of the parts instead of comparing them against an equivalent thickness Gr/Ep standard.

In almost all cases with flat panels that had localized areas of above-average porosity, we were able to visually detect the location of "bad" areas prior to NDI. The NDI did allow us to quantify the porosity and verify what the visual inspection first observed.

Except for visual inspection, no attempts were initially made to perform NDI on the preforms prior to RTM. Once it became apparent that architectural anomalies were occurring in the interlock woven preforms, attempts were made to subject the preforms to additional inspection. The best available method for inspecting textile architectures was to dissect a section of the fabric to expose and identify the yarns in a unit cell. This proved to be a time consuming technique. If the architectural anomaly occurred in the interior of the preform, it proved to be difficult to locate and identify.

7.0 REFERENCES

1. Hsu, D.K. "Ultrasonic Measurements of Porosity in Woven Graphite Polyimide Composites," Review of Progress in Quantitative Nondestructive Evaluation, Vol 8b, pp. 1063-1067, Plenum Press, New York, 1989.
2. Hsu, D.K., "Quantitative Evaluation of CFRP Void Contents, using Ultrasonic Attenuation and Velocity in Japan, U.S. Conference on Composite Materials, Washington D.C., June 27-29, 1988, Technical Publishing Co Inc, 1989, pp 1015-1024.
3. Roberts, R.A., Review of Progress in Quantitative Nondestructive Evaluation, Vol 7b, pp.1053-1062, Plenum Press, New York, 1988.
4. Roberts, R.A., Review of Progress in Quantitative Nondestructive Evaluation, Vol 8b, pp.1559-1566, Plenum Press, New York, 1989.
5. K. Nelson, A. Falcone, H. Dursch, P. George, P. Mori and G. Way., "*Resin Transfer Molding Microcracking Study*", informal report, Boeing Defense & Space Group, Seattle, WA.

APPENDIX A

Examples of Vender Provided Certifications and Data

SPECIMEN TYPES

A - 1/8" x 1.5" x 24"

B - 1/8" x 12" x 24"

C - 1/4" x 12" x 24"

BOEING BRAID STUDY SUMMARY OF FIBER ARCHITECTURES FOR FLAT PANEL PREFORMS

ARCHITECTURE - SLL			
SPECIMEN TYPE->	A	B	C
NO. OF CARRIERS	24	144	144
BIAS YARN SIZE	6 K	6 K	8 K
AXIAL YARN SIZE	30 K	30 K	30 K
BRAID ANGLE (DEG)	70	70	70
MANDREL DIA (IN)	0.891	5.25	5.25
NO OF PLYES	4	4	8
TOTAL FIBER VOLUME	52.3%	56.0%	54.5%
BIAS FIBER CONTENT	54%	54%	54%
AXIAL FIBER CONTENT	46%	46%	46%
AVE BIAS END COUNT (E/IN)	11.7	12.5	12.2
AVE AXIAL END COUNT (E/IN)	4.1	4.3	4.2

ARCHITECTURE - LLS			
SPECIMEN TYPE->	A	B	C
NO. OF CARRIERS	32	144	144
BIAS YARN SIZE	18 K	15 K	15 K
AXIAL YARN SIZE	42 K	36 K	36 K
BRAID ANGLE (DEG)	45	45	45
MANDREL DIA (IN)	0.891	4.75	4.75
NO OF PLYES	2	3	6
TOTAL FIBER VOLUME	49.8%	55.5%	54.2%
BIAS FIBER CONTENT	55%	54%	54%
AXIAL FIBER CONTENT	45%	46%	46%
AVE BIAS END COUNT (E/IN)	7.1	6.7	6.5
AVE AXIAL END COUNT (E/IN)	5.3	4.7	4.6

ARCHITECTURE - LLL			
SPECIMEN TYPE->	A	B	C
NO. OF CARRIERS	16	72	72
BIAS YARN SIZE	15 K	15 K	15 K
AXIAL YARN SIZE	87 K	75 K	75 K
BRAID ANGLE (DEG)	73	70	70
MANDREL DIA (IN)	0.891	4.75	4.75
NO OF PLYES	2	3	6
TOTAL FIBER VOLUME	50.9%	57.8%	56.3%
BIAS FIBER CONTENT	54%	54%	54%
AXIAL FIBER CONTENT	46%	46%	46%
AVE BIAS END COUNT (E/IN)	8.6	6.9	6.8
AVE AXIAL END COUNT (E/IN)	2.7	2.4	2.3

ARCHITECTURE - LSS			
SPECIMEN TYPE->	A	B	C
NO. OF CARRIERS	32	144	144
BIAS YARN SIZE	15 K	15 K	15 K
AXIAL YARN SIZE	6 K	6 K	6 K
BRAID ANGLE (DEG)	45	45	45
MANDREL DIA (IN)	0.891	4.75	4.75
NO OF PLYES	4	5	10
TOTAL FIBER VOLUME	52.1%	57.3%	56.0%
BIAS FIBER CONTENT	88%	88%	88%
AXIAL FIBER CONTENT	12%	12%	12%
AVE BIAS END COUNT (E/IN)	7.5	6.7	6.5
AVE AXIAL END COUNT (E/IN)	5.5	4.7	4.6



Textile Technologies, Inc.
A subsidiary of Advanced Composite Products, Inc.

Corporate Office
2800 Turnpike Drive
Hatboro, PA 19040
215/443-5325
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P.O. Box 1186
Culver City, CA 90232-1186
310-859-9028
Fax: 310/859-3977

4/15/92

Boeing Commercial
North Field Receiving Area
6900 Ellis Avenue, South
Bldg. 3-360, Door E-3
Seattle, WA 98108

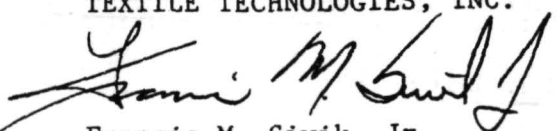
Re: Parts: 4 1/2 panels
Style: 12"wide OS-1
Cust. No.: L-858021-6970
Date P.O.: 1/28/92
Graphite
Size : 6K,12K,24K
Graphite
Mfg. : HERCULES

Dear Tony,

Attached is a copy of the average end item report for the fabric and part (s) forwarded this date.

The parts were woven using 100% graphite yarns as indicated above in both warp and filling directions. Included with this correspondence is yarn certification (s) as furnished by the supplier.

Very truly yours,
TEXTILE TECHNOLOGIES, INC.


Francis M. Siwik, Jr.
Quality Assurance Manager

TEST REPORT ON END ITEM

LABORATORY: TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 12"WIDE TS-2 PANELS

SPECIFICATION: CUSTOMER P.O. & TTI WA# 7045

QUANTITY: 3 1/2 panels

TESTING COMPLETED: 4/3/92

TESTS	LOT AVERAGE	REQUIREMENTS
WEIGHT (GM/M ²)	6539.36=57% FIBER VOLUME	55-60%FV
THICKNESS	.251"	
ENDS PER INCH	18	18
PICKS PER INCH	21	20
WIDTH (INCH)	12.375"	12.0"min
"X" PERCENTAGE	56%	55-60% TARGET
"Y" PERCENTAGE	38.1%	30-40% TARGET
"Z" PERCENTAGE	5.8%	10%max

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON T.T.I. LOT # 7045

CONTAINING YARDS OF ABOVE ITEMS, PURCHASE ORDER NUMBER

L-858021-6970.


QUALITY ASSURANCE MANAGER

TEST REPORT ON END ITEM

LABORATORY: TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 12"wide LS-1 multilayer panels

SPECIFICATION: CUSTOMER P.O.&TTI WA# 7043

QUANTITY: 4 1/2 panels(6.75 yds.)

TESTING COMPLETED: 2/25/92

TESTS	LOT AVERAGE	REQUIREMENTS
WEIGHT (GM/M ²)	6354.41=55.7% FV	55-60 FIBER VOLUME
THICKNESS	.340	
ENDS PER INCH	14 SURFACE	14
PICKS PER INCH	13 SURFACE	13
WIDTH (INCH)	12.25"	12.00"min.
"X" PERCENTAGE	58.6%	55-60 TARGET
"Y" PERCENTAGE	34.5%	30-40 TARGET
"Z" PERCENTAGE	6.8%	10%max.

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON

T.T.I. LOT # 7043

CONTAINING 6.75 YARDS OF ABOVE ITEMS, PURCHASE ORDER NUMBER

L-858021-6970.


QUALITY ASSURANCE MANAGER

TEST REPORT ON END ITEM

LABORATORY: TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 12" wide TS-1 multilayer panels

SPECIFICATION: CUSTOMER P.O. & TTI WA#7042

QUANTITY: 4 1/2 panels (6.75yds.)

TESTING COMPLETED: 2/25/92

TESTS	LOT AVERAGE	REQUIREMENTS
WEIGHT (GM/M ²)	6476.34=56.7% FV	55-60% FIBER VOLUME
THICKNESS	.331	
ENDS PER INCH	14 SURFACE	14
PICKS PER INCH	13 SURFACE	13
WIDTH (INCH)	12.50"	12.00"min.
"X" PERCENTAGE	57%	55-60 TARGET
"Y" PERCENTAGE	33%	30-40 TARGET
"Z" PERCENTAGE	9.8%	10%max

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON T.T.I. LOT # 7042

CONTAINING 6.75 YARDS OF ABOVE ITEMS, PURCHASE ORDER NUMBER

L-858021-6970.


QUALITY ASSURANCE MANAGER

TEST REPORT ON END ITEM

LABORATORY: TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 3" wide / 1"thick-Through the Thickness Panel

SPECIFICATION: Customer P.O. & TTI WA # 7065

QUANTITY: 1-12" part

TESTING COMPLETED: 7-15-92

TESTS	LOT AVERAGE	REQUIREMENTS
FIBER VOLUME	66% @ 1" cure ply 57.5% @ 1.157" 48.3% as woven	55-60 TARGET
THICKNESS	1.375"	
ENDS PER INCH	10.3 surface	10.5 surface
PICKS PER INCH	14.0 surface	15.0 surface
WIDTH (INCH)	3.0"	3.0"TARGET
"X" PERCENTAGE	51%	55-60%
"Y" PERCENTAGE	32%	30-40%
"Z" PERCENTAGE	17%	10% TARGET

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON T.T.I. LOT # 7065

CONTAINING 1-12" part OF ABOVE ITEMS, PURCHASE ORDER NUMBER
L858021.


QUALITY ASSURANCE MANAGER

TEST REPORT ON END ITEM

LABORATORY: TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 3"wide / 1"thick.-Layer to Layer panel

SPECIFICATION: Customer P.O. & TTI WA # 7066

QUANTITY: 1-12"part

TESTING COMPLETED: 7-15-92

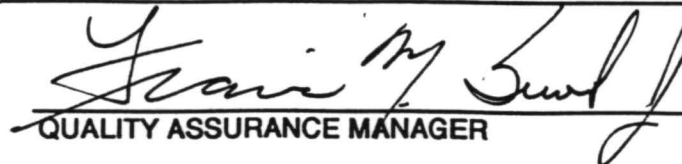
TESTS	LOT AVERAGE	REQUIREMENTS
FIBER VOLUME	60% @ 1"core ply 57.5% @ 1.053" 48.3% as woven	55-60% TARGET
THICKNESS	1.250"	
ENDS PER INCH	10.5 surface	10.5 surface
PICKS PER INCH	14.8 surface	15.0 surface
WIDTH (INCH)	3.0625"	3.0" TARGET
"X" PERCENTAGE	52%	55-60%
"Y" PERCENTAGE	33%	30-40%
"Z" PERCENTAGE	15%	10% TARGET

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON T.T.I. LOT # 7066

CONTAINING 1-12" PART OF ABOVE ITEMS, PURCHASE ORDER NUMBER

L858021.


QUALITY ASSURANCE MANAGER

TEST REPORT ON END ITEM

LABORATORY: TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 3"wide / 1"thick.-Orthogonal panel

SPECIFICATION: Customer P.O. & TTI WA # 7067

QUANTITY: 1-12"panel

TESTING COMPLETED: 7-15-92

TESTS	LOT AVERAGE	REQUIREMENTS
FIBER VOLUME	63% @ 1" cure ply 57.5% @ 1.105" 53.4% as woven	55-60% TARGET
THICKNESS	1.1875"	
ENDS PER INCH	10 surface	10.5 surface
PICKS PER INCH	13 surface	15.0 surface
WIDTH (INCH)	3.125"	3.0" Target
"X" PERCENTAGE	50%	55-60%
"Y" PERCENTAGE	30%	30-40%
"Z" PERCENTAGE	20%	10% TARGET

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON T.T.I. LOT # 7067

CONTAINING 1-12" PART OF ABOVE ITEMS, PURCHASE ORDER NUMBER

L858021.


QUALITY ASSURANCE MANAGER

TEST REPORT ON END ITEM

LABORATORY: TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 5" wide LS-1 panels

SPECIFICATION: Customer P.O. & TTI WA # 7083

QUANTITY: 14-2 ft. parts

TESTING COMPLETED: 10-15-92

TESTS	LOT AVERAGE	REQUIREMENTS
FIBER VOLUME	56.22% @ .25" cure ply	55-60%
THICKNESS	.320"	
ENDS PER INCH	14.6 surface	14.0 \pm 1.0 surface
PICKS PER INCH	13.0 surface	13.0 \pm 1.0 surface
WIDTH (INCH)	5.0625"	5.0 \pm 0.25"
"X" PERCENTAGE	60%	55-60% Target
"Y" PERCENTAGE	33.4%	30-40%
"Z" PERCENTAGE	6.6%	10% max

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON T.T.I. LOT # 7083

CONTAINING 9 YARDS OF ABOVE ITEMS, PURCHASE ORDER NUMBER

Remake of L-858021-6970.


QUALITY ASSURANCE MANAGER

TEST REPORT ON END ITEM

LABORATORY:

TEXTILE TECHNOLOGIES, INC.
2800 TURNPIKE DRIVE
HATBORO, PA. 19040

TEST REPORT

PRODUCT: 12" WIDE OS-1 PANELS

SPECIFICATION: CUSTOMER P.O. & TTI WA# 7041

QUANTITY: 4 1/2 panels

TESTING COMPLETED: 4/3/92

TESTS	LOT AVERAGE	REQUIREMENTS
WEIGHT (GM/M ²)	6214.51=56% FIBER VOLUME	55-60% FV
THICKNESS	.283"	
ENDS PER INCH	14 SURFACE	14
PICKS PER INCH	12.7 SURFACE	13
WIDTH (INCH)	12.187"	12.0"min
"X" PERCENTAGE	59%	55-60%TARGET
"Y" PERCENTAGE	33.5%	30-40%TARGET
"Z" PERCENTAGE	7.4%	10%max

I CERTIFY THAT THE TEST RESULTS IN THIS REPORT ARE SUBMITTED AS

REPRESENTING TESTING PERFORMED ON

T.T.I. LOT # 7041

CONTAINING

YARDS OF ABOVE ITEMS, PURCHASE ORDER NUMBER

L-858021-6970.


QUALITY ASSURANCE MANAGER



Amoco Performance Products, Inc.
P.O. Box 849
Greenville, South Carolina 29602
803-277-5720

THORNEL® CARBON FIBER CERTIFICATION

DATE: DECEMBER 28, 1991

CUSTOMER: TEXTILE TECHNOLOGY
2800 TURNPIKE DRIVE
HATBORO, PA. 19040
ATTN: STEVE ZAWISLAK

CUSTOMER REFERENCE NUMBER: 7656

APPI REFERENCE NUMBER: 85935901

PRODUCT: T-300 1K GRADE 309 ST

SIZING: UC 309

TWIST: STANDARD TWIST

QUANTITY (LBS.): 249.20

DATE SHIPPED: 1/03/92

THE MATERIAL SHIPPED IN THIS ORDER IS IN COMPLIANCE WITH SPC 34569, REV. E; WITH EXCEPTIONS DATED 12/19/91.

THE AVERAGE PHYSICAL PROPERTIES OF THE LOTS INCLUDED IN THIS SHIPMENT, BASED ON RANDOM LOT SAMPLINGS, ARE LISTED BELOW:

Mary C. Bruce
QUALITY ASSURANCE DEPT.

TRACE NUMBER	ELONGATION* %	YIELD (g/m)	FIBER DENSITY (g/cc)	TENSILE STRENGTH (psi X 10 ³)	YOUNG'S MODULUS (psi X 10 ⁶)	SIZING (wt. %)
220113	1.6	0.0660	1.770	553	34.3	1.20

*ELONGATION IS A CALCULATED VALUE BASED ON T.S./MOD. X 100

**MATERIAL MANUFACTURED IN JAPAN FOR APPI.



7041 7042 7043
7044 7045 7046

Hercules Advanced Materials &
Systems Company
Composite Products Group
Bacchus Works
Magna, Utah 84044-0098
(801) 250-5911

CERTIFICATE OF ANALYSIS

03 JANUARY 1992

Customer: TEXTILE TECHNOLOGIES
Purchase Order No: 7545
Specification: HS-AD-584, Rev. N
Material: Graphite Fiber, AS4-G (12K)
Quantity: 220.82 LBS. NET WT. (37 SPOOLS)
Lot No: 787-4M
Manufactured: 25 June 1991

Fiber Properties

	<u>Spec Req</u>	<u>Lot Average</u>
FLA Short Beam Shear, ksi	15 minimum	18
FLA Tensile Str., ksi*	450 minimum	541
FLA Tensile Mod., ksi*	32 - 35	34
Wt./Unit Length, lb/in x 10 ⁻⁶	45.50-50.50	46.59
Density, lb/in ³	0.0625-0.0660	0.0653
Twist, T/inch	0.8 maximum	0.0
Sizing Content, %	Report	0.4

*Data normalized to 100% Fiber Volume.

J. A. Rasmussen
J.A. Rasmussen, Plant 3
QUALITY CONTROL

JAR:rcs
3077p.12-20
CA307720091589
CP05087-1-1-4



7041 7042 7043
7044 7045 7046

Hercules Advanced Materials &
Systems Company
Composite Products Group
Bacchus Works
Magna, Utah 84044-0098
(801) 250-5911

CERTIFICATE OF ANALYSIS

03 JANUARY 1992

Customer: TEXTILE TECHNOLOGIES
Purchase Order No: 7545
Specification: HS-AD-584, Rev. N
Material: Graphite Fiber, AS4-G (12K)
Quantity: 111.84 LBS. NET WT. (18 SPOOLS)
Lot No: 787-4W
Manufactured: 30 August 1991

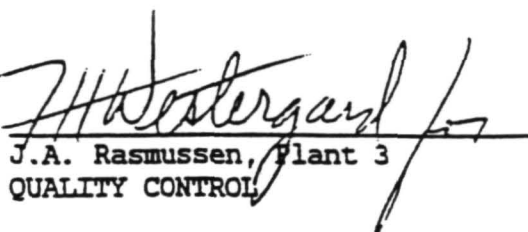
Fiber Properties

	<u>Spec Req</u>	<u>Lot Average</u>
FLA Short Beam Shear, ksi	15 minimum	19
FLA Tensile Str., ksi*	450 minimum	544
FLA Tensile Mod., msi*	32 - 35	33
Wt./Unit Length, lb/in x 10 ⁻⁶	45.50-50.50	48.36
Density, lb/in ³	0.0625-0.0660	0.0645
Twist, T/inch	0.8 maximum	0.0
Sizing Content, %	Report	0.5

*Data normalized to 100% Fiber Volume.

For Information Only

	<u>Requirement</u>	<u>Lot Average</u>
Tow Tensile Str., ksi	Report	584
Tow Tensile Mod., msi secant	Report	32
Tow Elongation, %	Report	1.65


J.A. Rasmussen, Plant 3
QUALITY CONTROL



7044 7045 7046

Hercules Advanced Materials &
Systems Company
Composite Products Group
Bacchus Works
Magna, Utah 84044-0098
(801) 250-5911

CERTIFICATE OF ANALYSIS

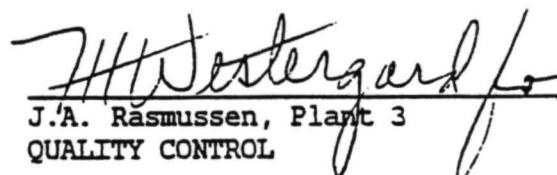
03 JANUARY 1992

Customer: TEXTILE TECHNOLOGIES
Purchase Order No: 7545
Specification: HS-AD-584, Rev. N
Material: Graphite Fiber, AS4-G (6K)
Quantity: 71.10 LBS. NET WT. (34 SPOOLS)
Lot No: 480-5C
Manufactured: 11 June 1991

Fiber Properties

	<u>Spec Req</u>	<u>Lot Average</u>
FLA Short Beam Shear, ksi	15 minimum	18
FLA Tensile Str., ksi*	450 minimum	531
FLA Tensile Mod., ksi*	32 - 35	33
Wt./Unit Length, lb/in x 10 ⁻⁶	22.75-25.25	23.75
Density, lb/in ³	0.0625-0.0660	0.0651
Twist, T/inch	0.8 maximum	0.0
Sizing Content, %	Report	1.1

*Data normalized to 100% Fiber Volume.


J.A. Rasmussen, Plant 3
QUALITY CONTROL

JAR:rcs
3077p.13-22
CA307722091589
CP05087-2-1-4

APPENDIX B

Bibliography



Boeing Technical Libraries

Bibliography

NONDESTRUCTIVE EVALUATION OF TEXTILE COMPOSITES

Please be reminded:

The Library will send you the full texts of any or all items necessary for your research. While in most instances the materials will be provided from the Boeing Library collection, in some cases we must go to outside sources. The average costs for obtaining outside materials is \$15.00 per item and will take additional time to obtain. Please review your selections accordingly.

Boeing Support Services

X-27544 REV 5/91

BOEINGTECHNICAL
LIBRARIES

LIBRARY LITERATURE SEARCH

SEARCH No. 91-1902

REQUESTOR John Linn

DOBIS USER No. 8558

ORGN 2-4886

M/S 85-08

PHONE 773-5725

SUBJECT:

NONDESTRUCTIVE EVALUATION OF TEXTILE COMPOSITES

SEARCH TERMS:

Nondestructive test(s)
Nondestructive testing
Nondestructive evaluation(s)
Nondestructive investigation(s)
NDI
NDE
NDT
Shearography
Radiography
Infrared inspection
Ultrasonic test(s)
Ultrasonic testing
Eddy currents

Composite materials
Composite(s)
Textile(s)
Fabric(s)
Woven
Knitted
Braided

SOURCES SEARCHED:

DATES OF COVERAGE:

1986-

Aerospace Database
Compendex
Inspec
Engineered Materials Abst.
NTIS
DTIC Tech. Rept..
Textile Technology Digest
World Textiles

NOTE: The citations on pages 1-28 are ones that deal with textiles or fabrics. Starting on page 29 are citations of a more general nature. These do not mention fabrics or textiles specifically, but I thought they might be of some interest.

TO OBTAIN PUBLICATIONS: Mark the references wanted and return the marked search with this sheet to the library.

SEARCH ANALYST

Rick Curtis

DATE

1/3/92

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21/5/1 (Item 1 from file: 108)

1806481 A92-10126

International SAMPE Symposium and Exhibition, 36th, San Diego, CA, Apr. 15-18, 1991, Proceedings. Books 1 & 2

STINSON, JIM (Aerojet, Propulsion Div., Sacramento, CA); ADSIT, RAY (Rohr Industries, Inc., Chula Vista, CA); GORDANINEJAD, FARAMARZ (Nevada, University, Reno), EDS.

Covina, CA, Society for the Advancement of Material and Process Engineering (Science of Advanced Materials and Process Engineering Series. Vol. 36), 1991, p. Book 1, 1208 p.; book 2, 1216 p. For individual items see A92-10127 to A92-10285.

Publication Date: 1991

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PROCEEDINGS

Journal Announcement: IAA9201

This symposium presents papers in the fields of the design and development of space system structures, advanced textile preforming, low-cost processing of materials, and nondestructive testing. Also presented are adhesive and bonding technologies, resin transfer molding, filament winding, high-temperature composites, thermoplastic material properties, composites for marine environments, and thermoplastic processes and applications. (R.E.P.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *COMPOSITE MATERIALS; *CONFERENCES; *MATERIALS SCIENCE; *TECHNOLOGY ASSESSMENT; ADHESIVE BONDING; ADHESIVES; FABRICATION; FILAMENT WINDING; LARGE SPACE STRUCTURES; MECHANICAL PROPERTIES; MOLDING MATERIALS; NONDESTRUCTIVE TESTS; PULTRUSION; QUALITY CONTROL; REFRACTORY MATERIALS; RESIN MATRIX COMPOSITES; SYNTHETIC RESINS; TEXTILES; THERMOPLASTIC RESINS
Subject Classification: 7523 Chemistry & Materials--General (1975-)

21/5/2 (Item 2 from file: 108)

1792971 N91-28292

Damage development under compression-compression fatigue loading in a stitched uniwoven graphite/epoxy composite material

Interim Report No. 86

VANDERMEY, NANCY E.; MORRIS, DON H.; MASTERS, JOHN E.

Virginia Polytechnic Inst. and State Univ., Blacksburg. Dept. of Engineering Science and Materials.

Publication Date: Jul. 1991 126P.

Report No.: NASA-CR-188693; NAS 1.26:188693; CCMS-91-16; VPI-E-91-14

Contract No.: NAG1-343

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Documents available from AIAA Technical Library

Other Availability: NTIS HC/MF A07

Journal Announcement: STAR9120

Damage initiation and growth under compression-compression fatigue loading were investigated for a stitched uniweave material system with an underlying AS4/3501-6 quasi-isotropic layup. Performance of unnotched specimens having stitch rows at either 0 degree or 90 degrees to the loading direction was compared. Special attention was given to the effects of stitching related manufacturing defects. Damage evaluation techniques included edge replication, stiffness monitoring, x-ray radiography, residual compressive strength, and laminate sectioning. It was found that the manufacturing defect of inclined stitches had the greatest adverse effect on material performance. Zero degree and 90 degree specimen performances were generally the same. While the stitches were the source of damage initiation, they also slowed damage propagation both along the length and across the width and affected through-the-thickness damage growth. A pinched layer zone formed by the stitches particularly affected damage initiation and growth. The compressive failure mode was transverse shear for all specimens, both in static compression and fatigue cycling effects. (Author)

Descriptors: *COMPRESSIBILITY; *COMPRESSIVE STRENGTH; *CRACK INITIATION; *CRACK PROPAGATION; *DAMAGE; *DEFECTS; *FAILURE MODES; *GRAPHITE-EPOXY COMPOSITES; *LAMINATES; *RESIDUAL STRENGTH; *TEXTILES; *WEAVING; CYCLES; DAMAGE ASSESSMENT; HAZARDS; LAY-UP; MANUFACTURING; RADIOGRAPHY; STIFFNESS; X RAYS

Subject Classification: 7524 Composite Materials (1975-)

COSATI Code: 11D Composite Materials

21/5/3 (Item 3 from file: 108)

1766334 N91-19461

Mechanical behavior of a ceramic matrix composite material

M.S. Thesis Final Report

GROSSKOPF, PAUL P.; DUKE, JOHN C., JR.

Virginia Polytechnic Inst. and State Univ., Blacksburg. Dept. of Engineering Science and Mechanics.

Publication Date: Feb. 1991 145P.

Report No.: NASA-CR-187072; NAS 1.26:187072

Contract No.: NAG3-172

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: THESIS

Documents available from AIAA Technical Library

Other Availability: NTIS HC/MF A07

Journal Announcement: STAR9111

Monolithic ceramic materials have been used in industry for hundreds of years. These materials have proven their usefulness in many applications, yet, their potential for critical structural applications is limited. The existence of an imperfection in a monolithic ceramic on the order of several microns in size may be critical, resulting in catastrophic failure.

To overcome this extreme sensitivity to small material imperfections, reinforced ceramic materials were developed. A ceramic matrix which has been reinforced with continuous fibers is not only less sensitive to microscopic flaws, but is also able to sustain significant damage without suffering catastrophic failure. A borosilicate glass reinforced with

several layers of plain weave silicon carbide cloth (Nicalon) was studied. The mechanical testing which was performed included both flexural and tensile loading configurations. This testing was done not only to determine the material properties, but also to initiate a controlled amount of damage within each specimen. Several nondestructive testing techniques, including acousto-ultrasonics (AU), were performed on the specimens periodically during testing. The AU signals were monitored through the use of an IBM compatible personal computer with a high speed data acquisition board. Software was written which manipulates the AU signals in both the time and frequency domains, resulting in quantitative measures of the mechanical response of the material. The measured AU parameters are compared to both the mechanical test results and data from other nondestructive methods including ultrasonic C-scans and penetrant enhanced x ray radiography. (Author)

Descriptors: *ACOUSTICS; *CERAMIC MATRIX COMPOSITES; *CERAMICS; *DEFECTS; *FAILURE ANALYSIS; *FIBER COMPOSITES; *MECHANICAL PROPERTIES; *NONDESTRUCTIVE TESTS; *ULTRASONIC FLAW DETECTION; BOROSILICATE GLASS; DAMAGE ASSESSMENT; DATA ACQUISITION; FABRICS; PENETRANTS; RADIOGRAPHY; SILICON CARBIDES; STRUCTURAL DESIGN

Subject Classification: 7538 Quality Assurance & Reliability (1975-)
COSATI Code: 14D Reliability

21/5/4 (Item 4 from file: 108)

1701246 N90-18513

Instrumented impact testing of fabric-reinforced composite materials
Research and Development Report

JUSKA, T. D.; CRANE, R. M.; MIXON, T.

David Taylor Research Center, Bethesda, MD. Dept. of Ship Materials
Engineering

Publication Date: May 1989 43P.

Publication Note: Sponsored by Naval Oceanographic Office

Report No.: AD-A216764; DTRC/SME-89-20

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Documents available from AIAA Technical Library

Other Availability: NTIS HC A03/MF A01

Journal Announcement: STAR9011

Instrumented impact and ultrasonic inspection were used to assess the impact damage resistance of six fabric-reinforced laminates. Polyester and vinylester resins reinforced with woven roving, biaxial reinforcement, and glass/Kevlar hybrid were evaluated. Biaxial fabric reinforced resins had the best impact resistance. This determination is based on the ability of these materials to survive impact with the lowest friction of impact energy resulting in damage. In addition laminates with biaxial reinforcement had comparable damage areas to the other materials. (GRA)

Source of Abstract/Subfile: DTIC

Descriptors: *FABRICS; *IMPACT DAMAGE; *IMPACT TESTS; *LAMINATES; *POLYESTER RESINS; *REINFORCING MATERIALS; AXIAL STRESS; FRICTION; IMPACT STRENGTH; ULTRASONIC TESTS

Subject Classification: 7524 Composite Materials (1975-)

COSATI Code: 11D Composite Materials

21/5/5 (Item 5 from file: 108)

1620318 N89-13631

Detection and characterization of porosity in ceramic/ceramic composites

WALTER, J. B.; LOTT, L. A.

Idaho National Engineering Lab., Idaho Falls.

Publication Date: Jul. 1988 32P.

Report No.: DE88-016965; EGG-MS-8179

Contract No.: DE-AC07-76ID-01570

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Documents available from AIAA Technical Library

Other Availability: NTIS HC A03/MF A01

Journal Announcement: STAR8905

Ceramic composites are an important new type of material being developed for applications requiring high strength at high temperatures. This report focuses on composites of a SiC fabric reinforced SiC matrix formed by chemical vapor infiltration. This material is characterized by extensive porosity, which is known to limit its strength. Effective methods of nondestructively detecting and characterizing porosity in the material are needed. This is a challenging task for ultrasonics because of the high levels of porosity (greater than 10 percent) found in the material and because of the intrinsic heterogeneity and anisotropy of the material, all of which strongly affect ultrasonic propagation. Techniques are described for measuring ultrasonic attenuation, transmitted energy, and propagation velocity using through transmission. Measurements are included which show correlation with the material porosity. A mathematical model was successfully developed to help understand the measurements and to permit extrapolation of the results to other sample sets. A comparison of the model to the measurements is reported. Implications of the model on the detection and resolution of individual voids and on distinguishing them from variations in the general porosity of the material are considered. (DOE)

Source of Abstract/Subfile: DOE

Descriptors: *CERAMICS; *COMPOSITE MATERIALS; *DETECTION; *FABRICS; *INFILTRATION; *NONDESTRUCTIVE TESTS; *POROSITY; *SILICON CARBIDES; *VAPORS; ATTENUATION; CHARACTERIZATION; MATHEMATICAL MODELS; MONTE CARLO METHOD; VELOCITY

Subject Classification: 7527 Nonmetallic Materials (1975-)

21/5/6 (Item 6 from file: 108)

1609526 N89-10129

Physical principles of ultrasonic non-destructive evaluation of advanced composites

Semiannual Progress Report, 15 Mar. - 14 Sep. 1988

MILLER, JAMES G.

Washington Univ., St. Louis, Mo. Lab. for Ultrasonics.

Publication Date: Sep. 1988 19P.

Report No.: NASA-CR-180225; NAS 1.26:180225

Contract No.: NSG-1601

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Documents available from AIAA Technical Library

Other Availability: NTIS HC A03/MF A01

Journal Announcement: STAR8901

Results are presented from the continued investigations into the use of ultrasonic measurement techniques for the detection and characterization of porosity. The effects that bleeder cloth impressions (left after the cure process) have on the capability of polar backscatter to interrogate volume effects such as porosity are described. Some preliminary data regarding a comparison of phase sensitive and phase insensitive detection for materials characterization is presented. (Author)

Source of Abstract/Subfile: NASA STIF

Descriptors: *LAMINATES; *NONDESTRUCTIVE TESTS; *POROSITY; *SURFACE PROPERTIES; *ULTRASONIC TESTS; ANISOTROPY; BACKSCATTERING; COMPOSITE STRUCTURES; CURING; FABRICS; SIGNAL TRANSMISSION

Subject Classification: 7524 Composite Materials (1975-)

COSATI Code: 11D Composite Materials

21/5/7 (Item 7 from file: 108)

1548437 N88-11758

Transply crack density detection by acousto-ultrasonics

HEMANN, JOHN H.; BOWLES, KENNETH J.; KAUTZ, HAROLD; CAVANO, PAUL
(Cleveland State Univ., Ohio.)

National Aeronautics and Space Administration. Lewis Research Center,
Cleveland, Ohio.

Publication Date: 1987 10P.

Presentation Note: Presented at Acousto-Ultrasonics: Theory and
Application, Blacksburg, Va., 12-15 Jul. 1987

Report No.: NASA-TM-100224; E-3843; NAS 1.15:100224

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Other Availability: NTIS HC A02/MF A01

Journal Announcement: STAR8803

The acousto-ultrasonic method was applied to a PMR-15 8-harness, satin Celion 3000 fabric composite to determine the extent of transply cracking. A six-ply 0/90 laminate was also subjected to mechanical loading, which induced transply cracking. The stress wave factor (SWF) is defined as the energy contained in the received signal from a 2.25-MHz center frequency transducer. The correlation of the SWF with transply crack density is shown. (Author)

Source of Abstract/Subfile: NASA STIF

Descriptors: *ACOUSTIC EMISSION; *FIBER COMPOSITES; *GRAPHITE;
*MICROCRACKS; *NONDESTRUCTIVE TESTS; *ULTRASONIC TESTS; CARBON FIBERS;
FABRICS; LAMINATES; LOAD TESTS; POLYMER MATRIX COMPOSITES; STRESS WAVES

Subject Classification: 7524 Composite Materials (1975-)

COSATI Code: 11D Composite Materials

21/5/8 (Item 1 from file: 4)

03363247 INSPEC Abstract Number: A89052252

Title: 20th International SAMPE Technical Conference. Vol.20. Materials -
Processes: the Intercept Point

Editor(s): Chess, H.L.; Prosen, S.P.; Davis, J.W.; Heth, J.A.

Publisher: Soc. Adv. Mater. & Process Eng, Covina, CA, USA

Publication Date: 1988 Country of Publication: USA xvi + 727 pp.

ISBN: 0 938994 45 X

Conference Sponsor: Soc. Adv. Mater. & Process Enbg

Conference Date: 27-29 Sept. 1988 Conference Location: Minneapolis, MN, USA

Language: English Document Type: Conference Proceedings (CP)

Treatment: General, Review (G); Experimental (X)

Abstract: The following topics were dealt with: metal matrix composites; toughened polymers; adhesives and adhesions; C fibre reinforced C composites; thermoplastics; design and analysis; processing and fabrication techniques; fibre and fabric technology; NDT; high temperature polymers; hybrid composites.

Descriptors: adhesion; carbon fibre reinforced composites; composite materials; nondestructive testing; polymers

Identifiers: metal matrix composites; toughened polymers; adhesives; adhesions; thermoplastics; design; processing; fabrication techniques; fabric technology; NDT; high temperature polymers; hybrid composites; C fibre reinforced C composites

Class Codes: A0130C (Conference proceedings); A8120 (Other methods of preparation of materials); A8170C (Nondestructive testing); A8190 (Other topics in materials science)

Chemical Indexing:

CC el - C el (Elements - 1)

21/5/9 (Item 1 from file: 293)

067715 EMA Number: 9007-B2-D-0397

Instrumented Impact Testing of Fabric-Reinforced Composite Materials. Research and Development Report.

Juska, T D ; Crane, R M ; Mixon, T

David Taylor Research Center

Report No.: AD-A216 764/1/XAB p. Pp 43

Publication Date: May 1989

1989

Journal Announcement: 9007

Document Type: REPORT

Language: ENGLISH

Instrumented impact and ultrasonic inspection were used to assess the impact damage resistance of six fabric-reinforced laminates. Polyester and vinylester resins reinforced with woven roving, biaxial reinforcement, and glass/Kevlar hybrid were evaluated. Biaxial fabric reinforced resins had the best impact resistance. This determination is based on the ability of these materials to survive impact with the lowest friction of impact energy resulting in damage. In addition laminates with biaxial reinforcement and comparable damage areas to the other materials are examined.--GRAI

Descriptors: Polyester resins-- Composite materials; Vinyl ester resins-- Composite materials; Glass fibers-- Composite materials; Aramid fibers-- Composite materials; Hybrid composites-- Mechanical properties; Laminates -- Mechanical properties; Impact strength; Impact tests; Ultrasonic testing

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

21/5/10 (Item 2 from file: 293)

027324 EMA Number: 8802-B2-D-0054

✓ Analysis of Woven Fabrics for Reinforced Composite Materials. Final Report, 3 November 1982-30 April 1987.

Dow, N F ; Ramnath, V ; Rosen, B W

Materials Sciences

Report No.: N87-26991/6/GAR p. Pp 239

Publication Date: Apr. 1987

1987

Journal Announcement: 8802

Document Type: REPORT

Language: ENGLISH

The use of woven fabrics as reinforcements for composites is considered. Methods of analysis of properties are reviewed and extended, with particular attention paid to three-dimensional constructions having through-the-thickness reinforcements. Methodology developed is used parametrically to evaluate the performance potential of a wide variety of reinforcement constructions, including hybrids. Comparisons are made of predicted and measured properties of representative composites having biaxial and triaxial woven, and laminated tape lay-up reinforcements. Overall results are incorporated in advanced weave designs.--GRAI

Descriptors: Laminates-- Mechanical properties; Fabrics-- Mechanical properties; Mechanical properties; Nondestructive testing; Axial stress; Weaving-- Design

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

21/5/11 (Item 1 from file: 6)

1455559 NTIS Accession Number: AD-A218 911/6/XAB

On-Line X-ray Inspection of Materials and Structural Components Using Discrete Element X-ray Detectors for Digital Radiographic and Computed Tomographic Evaluation

(Final rept. 1 Aug 88-31 Jan 90)

Isaacson, B. G.

Bio-Imaging Research, Inc., Lincolnshire, IL.

Corp. Source Codes: 097106000; 416972

Sponsor: Army Research Office, Research Triangle Park, NC.

Report No.: ARO-25952.1-EG-SBI

Feb 90 55p

Languages: English

Journal Announcement: GRAI9013

NTIS Prices: PC A04/MF A01

Country of Publication: United States

Contract No.: DAAL03-88-C-0024

This project was designed to study the effectiveness of industrial computed tomography (CT) and digital radiography (DR) as inspection techniques for the evaluation of materials and structural components manufactured on-line. The results indicate that computed tomography is an appropriate technique if speed and cost are not critical considerations. Digital radiography is the faster technique, but provides less information about the material. Limited view tomography (LVT), which is a simplified form of computed tomography, was compared and found to provide a good compromise between computed tomography and digital radiography when a priori knowledge of material structure is available. For some material configurations, it provides virtually complete computed tomography data in a fraction of the time required for full view computed tomography data

collection and reconstruction. It offers the greatest potential for the productive cross-sectional characterization of composite materials. X-ray inspection; Radiography; Material evaluation; Discrete element detectors; Computed tomography; Tomography; Digital radiography; Composite materials; Epoxy glass material; Glass cloth with polyester matrix; Kelvar cloth polyvinylbutyral matrix. (jg)

Descriptors: *Composite materials; *Computerized tomography; Configurations; Costs; Data acquisition; Detectors; *Digital systems; Epoxy resins; Glass reinforced plastics; Glass textiles; Industries; Inspection; Online systems; *Radiography; Structural components; Test and evaluation; Tomography; X rays

Identifiers: NTISDODXA; NTISDODA

Section Headings: 94J (Industrial and Mechanical Engineering--Nondestructive Testing); 71F (Materials Sciences--Composite Materials); 41K (Manufacturing Technology--Engineering Materials)

26/5/1 (Item 1 from file: 108)

1755941 A91-23701

Advances in composite materials and structures (Book)

WANG, S. S. (Illinois, University, Urbana); RAJAPAKSE, Y. D. S. (U.S. Navy, Office of Naval Research, Arlington, VA), EDS.

New York, American Society of Mechanical Engineers, 1989, 164 p. For individual items see A91-23702 to A91-23717.

Publication Date: 1989

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: COLLECTED WORK; CONFERENCE PROCEEDINGS

Journal Announcement: IAA9108

Topics discussed in this volume include the damage and failure of fiber composite materials, the characterization of composites under thermal environment, the mechanical behavior and NDE of fiber composite materials, environmental effects in composites, life prediction for composite materials, analysis of composite materials and structures, and textile structural composites. Papers are presented on the impact and residual fatigue behavior of ARALL and AS6/5245 materials, thermal expansion and elastic anisotropy in single-crystal Al₂O₃ and SiC whiskers, damage accumulation and stiffness degradation in cross-ply graphite/epoxy composites, and transport properties of water in high-performance resin systems. Consideration is also given to the fatigue delamination growth in laminated composites, a rotordynamic analysis of filamentary wound composite shafts, and a model for nonlinear stress-strain behavior of two-dimensional composites with brittle matrices and wavy yarns. (I.S.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *COMPOSITE MATERIALS; *CONFERENCES; *FAILURE ANALYSIS; *FIBER COMPOSITES; *NONDESTRUCTIVE TESTS; ENVIRONMENT EFFECTS; FATIGUE TESTS; IMPACT TESTS; LAMINATES; SINGLE CRYSTALS; STRESS-STRAIN RELATIONSHIPS; TEMPERATURE EFFECTS; WHISKER COMPOSITES

Subject Classification: 7524 Composite Materials (1975-)

26/5/2 (Item 2 from file: 108)

1747286 A91-17620

The fatigue of organic matrix composite materials

CURTIS, P. T. (Royal Aerospace Establishment, Materials and Structures

Dept., Farnborough, England)

IN: Advanced composites (A91-17610 05-24). London, England and New York, Elsevier Applied Science, 1989, p. 331-367.

Publication Date: 1989 47 Refs.

Language: English

Country of Origin: United Kingdom Country of Publication: United Kingdom

Document Type: ANALYTIC OF COLLECTED WORK

Documents available from AIAA Technical Library

Journal Announcement: IAA9105

The fatigue behavior of various types of organic-matrix composite materials, including unidirectional and multidirectional laminated composites, fabric-based composites, short-fiber composite materials, and hybrid composites is examined, and methods used for testing the fatigue behavior of composite materials are described. Attention is given to the frequency effects during the fatigue of composite materials, with special consideration given to the effects of frequency on mechanical properties, edge-induced stresses, and stress concentrators such as notches, holes, fasteners, and impact damages. The origins of the compressive failure are discussed. Special consideration is given to techniques used for fatigue life prediction of composite materials and to considerations applied to structural designs using composites. (I.S.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *FATIGUE TESTS; *FIBER COMPOSITES; *FIBER ORIENTATION; *MECHANICAL PROPERTIES; *NONDESTRUCTIVE TESTS; *ORGANIC MATERIALS; CARBON

FIBER REINFORCED PLASTICS; COMPRESSION LOADS; FLEXING; LAMINATES; S-N DIAGRAMS; SHEAR PROPERTIES; STRESS CONCENTRATION

Subject Classification: 7539 Structural Mechanics (1975-)

26/5/3 (Item 3 from file: 108)

1699541 A90-28192

Evaluation of 3-D reinforcements in commingled, thermoplastic structural elements

ROSSI, GLENN T. (Boeing Helicopters, Philadelphia, PA)

IN: AHS, Annual Forum, 45th, Boston, MA, May 22-24, 1989, Proceedings (A90-28151 11-01). Alexandria, VA, American Helicopter Society, 1989, p. 509-515.

Publication Date: 1989 7 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA9011

Two damage-tolerance design concepts, z-direction stitched two-dimensional laminates and fully three-dimensional braided composites, which use commingled graphite thermoplastic yarns are studied experimentally and using a series of advanced NDE methods. Damage initiation occurred at slightly lower energy levels in the stitched compression-after-impact (CAI) specimens compared to unstitched specimens. Overall residual compressive strength was better for the stitched specimens. Stitched residual strength improved over that of unstitched specimens with increasing damage energy. The data on three-dimensional braided composites indicates that CAI strength is the same or better than

that in stitched two-dimensional fabric laminates using the same commingled yarn in each specimen. (C.D.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *AIRCRAFT CONSTRUCTION MATERIALS; *DELAMINATING; *FIBER COMPOSITES; *PLASTIC AIRCRAFT STRUCTURES; *THERMOPLASTIC RESINS; *THREE DIMENSIONAL COMPOSITES; BOEING AIRCRAFT; COMPUTER AIDED TOMOGRAPHY; NONDESTRUCTIVE TESTS; PEEK; RESIN MATRIX COMPOSITES

Subject Classification: 7524 Composite Materials (1975-)

26/5/4 (Item 4 from file: 108)

1672038 A89-54900

Ultrasonic evaluation of matrix cracking in graphite BMI

FULLER, MICHAEL D. (Martin Marietta Aero and Naval Systems, Baltimore, MD)

Society of Manufacturing Engineers, Fabricating Composites '88 Conference, Philadelphia, PA, Sept. 12-15, 1988. 14 p.

Publication Date: Sep. 1988 6 Refs.

Report No.: SME PAPER EM88-549

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: PREPRINT

Documents available from AIAA Technical Library

Journal Announcement: IAA8924

Two NDE methods developed and deployed for reliable, accurate detection and quantification of microcracking in the radii of precooler ducts made of graphite and Nextel bismaleimide (BMII) fibers are discussed. The first makes use of guided ultrasonic waves or Lamb waves; the other resembles traditional approaches made possible by zero impedance matching at the probe-duct interface. Conventional nondestructive testing techniques are shown to be inapplicable to this problem of fabric composite construction and the geometric constraints imposed by the radii. Acceptance criteria and reference standards are the most suitable means to meet the inspection requirements. The paper examines proof of principle demonstration through inspection procedure development, background material on the inspection requirement, and the unique inspection philosophy for this problem. (C.E.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *DUCTED BODIES; *GRAPHITE-POLYIMIDE COMPOSITES; *LAMB WAVES; *MATRIX MATERIALS; *MICROCRACKS; *ULTRASONIC FLAW DETECTION; BISMALIMIDE;

DUCTED FAN ENGINES; INSPECTION; NONDESTRUCTIVE TESTS; QUALITY CONTROL

Subject Classification: 7538 Quality Assurance & Reliability (1975-)

26/5/5 (Item 5 from file: 108)

1636793 A89-30551

American Society for Composites, Technical Conference, 3rd, Seattle, WA, Sept. 25-29, 1988, Proceedings

Conference sponsored by the American Society for Composites, University of Washington, and Boeing Co. Lancaster, PA, Technomic Publishing Co., Inc., 1988, 747 p. For individual items see A89-30552 to A89-30574, A89-30576 to A89-30608, A89-30610 to A89-30615.

Publication Date: 1988

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PROCEEDINGS

Journal Announcement: IAA8911

The present conference on state-of-the-art composite materials discusses topics in processing and manufacturing methods, biotechnology-related composites, the mechanics of composite materials, novel high-performance composites, matrix/reinforcement interfaces, composite impact and damage tolerance, reinforcement science and engineering advancements, internal stresses in composites, composite design and characterization methods, composite structures design and analysis, and composites fracture and fatigue behaviors. Attention is given to economic issues in composite manufacturing, energy principle-based yield criteria, composites for orthopedic applications, the fabrication of a low-cost missile structure, modeling the elastic properties of three-dimensional textile structural composites, rubber-toughened polycarbonates, shape-memory alloy-reinforced composites, and global-local FEM for composites analysis. (O.C.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *CONFERENCES; *DELAMINATING; *FIBER COMPOSITES; *MECHANICAL PROPERTIES; BIOTECHNOLOGY; COMPOSITE STRUCTURES; CREEP PROPERTIES; FATIGUE TESTS; FRACTURE MECHANICS; GRAPHITE-EPOXY COMPOSITES; LAMINATES; MANUFACTURING; MATERIALS TESTS; NONDESTRUCTIVE TESTS; RESIDUAL STRESS; RESIN MATRIX COMPOSITES; STRESS ANALYSIS; STRUCTURAL DESIGN; THERMOPLASTIC RESINS

Subject Classification: 7524 Composite Materials (1975-)

26/5/6 (Item 6 from file: 108)

1537373 A87-51729

Composites '86: Recent advances in Japan and the United States; Proceedings of the Third Japan-U.S. Conference on Composite Materials, Science University of Tokyo, Japan, June 23-25, 1986

KAWATA, KOZO; UMEKAWA, SOKICHI (Tokyo, Science University, Japan); KOBAYASHI, AKIRA (Tokyo, University, Japan), EDS.

Conference sponsored by the Japan Society for Composite Materials and Commemorative Association for the Japan World Exposition. Tokyo, Japan Society for Composite Materials, 1986, 908 p. For individual items see A87-51730 to A87-51807.

Publication Date: 1986

Language: English

Country of Origin: Japan Country of Publication: Japan

Document Type: CONFERENCE PROCEEDINGS

Journal Announcement: IAA8723

The present conference considers topics in the fields of composite reinforcement fibers and fabrics, composite matrix systems, impact and stress waves in composite solids, composite fatigue behavior, composite plate vibration, composite mechanical properties and stress analysis, and composite damage and fracture behavior. Also discussed are laminates and their joints, flexible composite systems, the compression/shear behavior of composites, ceramic-matrix composites, metal-matrix composites, composite fabrication methods, composites testing methods, composite materials design methods, fiber/matrix interfacial phenomena, metal-matrix composite interfaces, environmental effects on composites, and composite fabrication equipment design. (O.C.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *CONFERENCES; *FIBER REINFORCED COMPOSITES; *FRACTURE

MECHANICS; *MECHANICAL PROPERTIES; CARBON-CARBON COMPOSITES;
DAMAGE
ASSESSMENT; FATIGUE LIFE; IMPACT LOADS; JAPAN; MATRIX MATERIALS; METAL
MATRIX COMPOSITES; NONDESTRUCTIVE TESTS; REINFORCED PLATES;
REINFORCING
FIBERS; STRESS ANALYSIS; STRESS WAVES; STRUCTURAL DESIGN; STRUCTURAL
VIBRATION; UNITED STATES

Subject Classification: 7524 Composite Materials (1975-)

26/5/7 (Item 7 from file: 108)

1530391 N87-26224

Measurement of ultrasonic properties of ceramic/ceramic composite
materials

WALTER, JOHN B.; LOTT, LAYMAN A.

Edgerton, Germeshausen and Grier, Inc., Idaho Falls, Idaho.

Publication Date: Mar. 1987 18P.

Report No.: DE87-009721; EGG-SD-7621

Contract No.: DE-AC07-76ID-01570

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Documents available from AIAA Technical Library

Other Availability: NTIS HC A02/MF A01

Journal Announcement: STAR8720

Ceramic composites are an important new type of material being developed for applications requiring high strength at high temperatures. Considered here are composites of a SiC fabric reinforced SiC matrix formed by chemical vapor infiltration. An important aspect of this process is the formation of extensive porosity which is known to limit the strength of the material. Effective methods of nondestructively detecting and characterizing porosity in the material are needed. This is a challenging task for ultrasonics because of the high levels of porosity (typically 10 to 50%) found in the material and because of the intrinsic heterogeneity and anisotropy of the material, all of which strongly affect ultrasonic wave propagation. Techniques are described for measuring ultrasonic attenuation, transmitted energy, and propagation velocity using through-transmission. Measurements are included for a set of samples containing a range of porosity. It is concluded that the techniques are adequate to form a technical basis for developing effective ultrasonic NDE methods. (DOE)

Source of Abstract/Subfile: DOE

Descriptors: *CERAMIC MATRIX COMPOSITES; *NONDESTRUCTIVE TESTS;
*ULTRASONIC TESTS; POROSITY; REFRACTORY MATERIALS; SILICON CARBIDES

Subject Classification: 7527 Nonmetallic Materials (1975-)

26/5/8 (Item 1 from file: 293)

074343 EMA Number: 9011-B2-D-0717

Nondestructive Evaluation of Advanced Ceramic Composite Materials.

(Retroactive Coverage).

Walter, J B ; Lott, L A

EG&G Idaho

Fossil Energy Materials Program, Oak Ridge, Tennessee, USA, 19-21 May
1987

Report No.: ORNL/FMP-87/4 p. 168-184

Publ: Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA,
1987

Journal Announcement: 9011

Document Type: REPORT

Language: ENGLISH

Ceramic composites are an important new type of material being developed for applications requiring high strength at high temperatures. Considered here are composites of a SiC matrix reinforced with SiC fabric which is formed by chemical vapor infiltration of the fabric. An important aspect of this process is the formation of extensive porosity which limits the strength of the material. Effective methods of nondestructively detecting and characterizing porosity in the material are needed. This is a challenging task for ultrasonic techniques because of the high levels of porosity (typically 10-50%) found in the material and because of the intrinsic heterogeneity and anisotropy of the material, all of which strongly affect ultrasonic wave propagation. Through-transmission techniques for measuring ultrasonic properties are described, including the use of time delay spectrometry and laser generation of ultrasound. Acoustic properties and area scans are presented for samples containing a range of porosity. It is concluded that the techniques are adequate to form a technical basis for developing effective ultrasonic NDE methods. Graphs, Photomicrographs. 2 ref.--AA

Descriptors: Silicon carbide-- Composite materials; Ceramic fiber reinforced ceramics-- Nondestructive testing; Ultrasonic testing; Porosity; Chemical vapor deposition

Trade Name/Material Index(Identifier): Nicalon-- CABF

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

26/5/9 (Item 2 from file: 293)

072582 EMA Number: 9010-B2-D-0673

Ultrasonic Detection of Voids in Ceramic Composites.

Walter, J B ; Lott, L A

EG&G Idaho

Review of Progress in Quantitative Nondestructive Evaluation. Vol. 8B,
La Jolla, California, USA, 1-5 Aug. 1988

p. 1621-1626

Publ: Plenum Press, 233 Spring Street, New York, New York 10013, USA,
1989

Journal Announcement: 9010

Document Type: BOOK

Language: ENGLISH

The composite studied comprised a fibre-weave reinforcing fabric in a SiC matrix formed by an infiltration process conducive to high (10-50%) porosity and void formation. Detecting and characterizing these by ultrasound thermoelastically generated by a pulsed laser beam was investigated in depth to optimize the laser parameters and elucidate the mechanisms involved. The results show that, despite the complexity of highly porous ceramics as ultrasound-propagation media, voids, pore agglomerates, and porosity-content variations are detectable by through-transmission techniques, and that part of the laser-generated pulse actually penetrates. The material can thus be inspected without ablative surface damage. Graphs. 3 ref.--J.R.

Descriptors: Ceramic matrix composites-- Nondestructive testing; Silicon

carbide-- Composite materials; Laser processing; Ultrasonic testing; X ray analysis; Porosity

Trade Name/Material Index(Identifier): Nicalon-- CABF

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

26/5/10 (Item 3 from file: 293)

067710 EMA Number: 9007-B2-D-0392

Trans-Ply Crack Density Detection by Acousto-Ultrasonics.

Hemann, J H ; Cavano, P ; Kautz, H ; Bowles, K

Cleveland State University, NASA Lewis Research Center

Acousto-Ultrasonics: Theory and Application, Blacksburg, Virginia, USA,

12-15 July 1987

p. 319-325

Publ: Plenum Press, 233 Spring St., New York, New York 10013, USA, 1988

Journal Announcement: 9007

Document Type: BOOK

Language: ENGLISH

It is demonstrated that acousto-ultrasonics can be used to detect trans-ply cracks in graphite/PMR polyimide cross-ply and woven fabric laminates. Adams et al. have demonstrated experimentally that thermally induced trans-ply cracking occurs in graphite-epoxy cross-ply laminates for various laminate configurations. Ishikawa and Chou discuss the existence of trans-ply cracks in woven fabric composites. Thus, it is clear that trans-ply cracks do exist both in cross-ply and in woven fabrics, due to both mechanical loads and thermal cycling. Graphs, Photomicrographs.

3 ref.--AA

Descriptors: Ultrasonic testing; Polyimides-- Composite materials; Carbon fiber reinforced plastics-- Nondestructive testing; Laminates--

Nondestructive testing; Stress analysis; Cracks; Acoustic measurement

Trade Name/Material Index(Identifier): PMR-15-- PAN

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

26/5/11 (Item 1 from file: 6)

1441470 NTIS Accession Number: AD-A216 764/1/XAB

Instrumented Impact Testing of Fabric-Reinforced Composite Materials (Research and development rept)

Juska, T. D. ; Crane, R. M. ; Mixon, T.

David Taylor Research Center, Bethesda, MD. Ship Materials Engineering Dept.

Corp. Source Codes: 091012001; 418407

Report No.: DTRC/SME-89-20

May 89 43p

Languages: English

Journal Announcement: GRAI9009

NTIS Prices: PC A03/MF A01

Country of Publication: United States

Instrumented impact and ultrasonic inspection were used to assess the impact damage resistance of six fabric-reinforced laminates. Polyester and vinylester resins reinforced with woven roving, biaxial reinforcement, and glass/Kevlar hybrid were evaluated. Biaxial fabric reinforced resins had the best impact resistance. This determination is based on the ability of these materials to survive impact with the lowest friction of impact energy

resulting in damage. In addition laminates with biaxial reinforcement and comparable damage areas to the other materials. (AW)

Descriptors: Addition; Biaxial stresses; *Composite materials; Damage; Energy; Fabrics; Friction; Impact; *Impact strength; *Impact tests; Instrumentation; *Laminates; Polyester plastics; Polymers; Reinforcing materials; Resistance; Ultrasonic tests

Identifiers: NTISDODXA

Section Headings: 71F (Materials Sciences--Composite Materials); 41K (Manufacturing Technology--Engineering Materials)

26/5/12 (Item 2 from file: 6)

1387134 NTIS Accession Number: DE88016965/XAB

Detection and Characterization of Porosity in Ceramic/Ceramic Composites

Walter, J. B. ; Lott, L. A.

EG and G Idaho, Inc., Idaho Falls.

Corp. Source Codes: 046580000; 9507781

Sponsor: Department of Energy, Washington, DC.

Report No.: EGG-MS-8179

25 Jul 88 32p

Languages: English

Journal Announcement: GRAI8906; NSA1300

Portions of this document are illegible in microfiche products.

NTIS Prices: PC A03/MF A01

Country of Publication: United States

Contract No.: AC07-76ID01570

Ceramic composites are an important new type of material being developed for applications requiring high strength at high temperatures. This report focuses on composites of a SiC fabric reinforced SiC matrix formed by chemical vapor infiltration. This material is characterized by extensive porosity, which is known to limit its strength. Effective methods of nondestructively detecting and characterizing porosity in the material are needed. This is a challenging task for ultrasonics because of the high levels of porosity (>10%) found in the material and because of the intrinsic heterogeneity and anisotropy of the material, all of which strongly affect ultrasonic propagation. Techniques are described for measuring ultrasonic attenuation, transmitted energy, and propagation velocity using through transmission. Measurements are included which show correlation with the material porosity. A mathematical model was successfully developed to help understand the measurements and to permit extrapolation of the results to other sample sets. A comparison of the model to the measurements is reported. Implications of the model on the detection and resolution of individual voids and on distinguishing them from variations in the general porosity of the material are considered. 6 refs., 12 figs. (ERA citation 13:051665)

Descriptors: *Composite Materials; *Silicon Carbides; Attenuation; *Ceramics; Equations; *Mathematical Models; Monte Carlo Method; *Porosity; *Ultrasonic Testing; Velocity

Identifiers: ERDA/360202; ERDA/360203; ERDA/420500; ERDA/360602; NTISDE

Section Headings: 71D (Materials Sciences--Ceramics, Refractories, and Glass); 71F (Materials Sciences--Composite Materials)

26/5/13 (Item 3 from file: 6)

1297026 NTIS Accession Number: N88-11758/5/XAB

Transply Crack Density Detection by Acousto-Ultrasonics

Hemann, J. H. ; Bowles, K. J. ; Kautz, H. ; Cavano, P.
National Aeronautics and Space Administration, Cleveland, OH. Lewis
Research Center.

Corp. Source Codes: 019039001; ND315753

Report No.: NAS 1.15:100224; E-3843; NASA-TM-100224

1987 10p

Languages: English

Journal Announcement: GRAI8806; STAR2603

Presented at Acousto-Ultrasonics: Theory and Application, Blacksburg,
VA., July 12-15, 1987.

NTIS Prices: PC A02/MF A01

Country of Publication: United States

The acousto-ultrasonic method was applied to a PMR-15 8-harness, satin
Celion 3000 fabric composite to determine the extent of transply cracking.
A six-ply 0/90 laminate was also subjected to mechanical loading, which
induced transply cracking. The stress wave factor (SWF) is defined as the
energy contained in the received signal from a 2.25-MHz center frequency
transducer. The correlation of the SWF with transply crack density is
shown.

Descriptors: *Acoustic emission; *Fiber composites; *Graphite;
*Microcracks; *Nondestructive tests; *Ultrasonic tests; Carbon fibers;
Fabrics; Laminates; Load tests; Polymer matrix composites; Stress waves

Identifiers: NTISNASA

Section Headings: 71F (Materials Sciences--Composite Materials); 41K
(Manufacturing Technology--Engineering Materials); 41G (Manufacturing
Technology--Quality Control and Reliability); 94J (Industrial and
Mechanical Engineering--Nondestructive Testing)

26/5/14 (Item 4 from file: 6)

1277734 NTIS Accession Number: AD-A184 349/9/XAB

Solid State C-13 NMR (Carbon 13 Nuclear Magnetic Resonance)

Characterization of Textiles: Qualitative and Quantitative Analysis

(Technical rept. no. 3, Aug 86-Aug 87)

Colletti, R. F. ; Mathias, L. J.

University of Southern Mississippi, Hattiesburg. Dept. of Polymer
Science.

Corp. Source Codes: 020978011; 416198

27 Aug 87 16p

Languages: English

Journal Announcement: GRAI8724

NTIS Prices: PC A02/MF A01

Country of Publication: United States

Contract No.: N00014-86-K-0659

Cross-polarization magic angle spinning (CP/MAS) carbon 13 NMR was used
to qualitatively characterize textiles of various compositions. Rapid and
accurate determination of cotton/polyester blends was accomplished with
minimal sample preparation. Qualitative identification was demonstrated for
various fiber blends including mislabeled samples. This technique fabrics
and should extend to composite reinforcing materials and prepregs.

Descriptors: *Textiles; *Nuclear magnetic resonance; *Spectroscopy;
Carbon; Isotopes; Cotton; Polyester fibers; Synthetic fibers; Quantitative
analysis; Qualitative analysis; Inventory analysis; Cross polarization;
Textile industry; Chemical analysis; Costs; Nondestructive testing;
Specifications

Identifiers: Carbon 13; Prepreg; Magic angle spinning; NTISDODXA
Section Headings: 71I (Materials Sciences--Fibers and Textiles); 71F

31/5/1 (Item 1 from file: 108)

1726798 A90-47020

Observation of crack path in an SiC-SiC fibre composite by X-ray radiography and SEM

NAVARRE, G.; ROUAIS, J.-C.; ROUBY, D. (Lyon, Institut National des Sciences Appliquees, Villeurbanne, France)

Journal of Materials Science Letters (ISSN 0261-8028), vol. 9, June 1990, p. 636-638.

Publication Date: Jun. 1990

Language: English

Country of Origin: France Country of Publication: United Kingdom

Document Type: JOURNAL ARTICLE

Documents available from AIAA Technical Library

Journal Announcement: IAA9021

To better understand the nonlinear behavior of ceramic matrix composites due to complex damage processes, it is essential to visualize the different stages of damage during loading and fracture. In order to examine this damage, both nondestructive X-ray investigation and SEM were applied. The material evaluated is a bidirectional SiC-SiC composite, with woven cloths used as reinforcement, with each bundle consisting of nearly 150 SiC-Nicalon fibers. Radiographs are taken by means of an opacifiant (zinc iodide). It is concluded that an X-ray technique with opacifiant is a useful method for visualizing the principal fracture crack in the core specimen. (R.E.P.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *CERAMIC FIBERS; *CERAMIC MATRIX COMPOSITES; *CRACK PROPAGATION; *ELECTRON MICROSCOPY; *RADIOGRAPHY; *SILICON CARBIDES; DAMAGE

ASSESSMENT; FRACTURE MECHANICS; MICROSTRUCTURE; NONDESTRUCTIVE TESTS

Subject Classification: 7524 Composite Materials (1975-)

31/5/2 (Item 2 from file: 108)

1719585 A90-42372

Composites applications - The future is now

DROZDA, THOMAS J., ED. (Society of Manufacturing Engineers, Dearborn, MI)

Dearborn, MI, Society of Manufacturing Engineers, 1989, 475 p. No individual items are abstracted in this volume.

Publication Date: 1989

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: COLLECTED WORK

Journal Announcement: IAA9018

The present volume on the development status of advanced composites discusses resin-, ceramic- and metal-matrix composites, as well as tooling practices, testing and inspection methods, and novel applications. Attention is given to interface considerations in ceramic-matrix composites, applications of metal-matrix composites to military aircraft, advanced thermoplastic preforms, tooling for filament-winding processes, trapped-rubber molding methods, pultrusion for automotive applications, and composite-production tooling using CAD/CAM. Also discussed are expert

systems for composites inspection and repair, acoustographic high-speed NDE for composites, the design and production of a composite landing gear-retracting beam, braided composite structures, and the uses of composites in orthopedics. (O.C.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *CERAMIC MATRIX COMPOSITES; *FIBER COMPOSITES; *MECHANICAL PROPERTIES; *METAL MATRIX COMPOSITES; *RESIN MATRIX COMPOSITES; ALUMINUM

OXIDES; COMPOSITE STRUCTURES; COMPUTER AIDED DESIGN; COMPUTER AIDED MANUFACTURING; CURING; DAMAGE ASSESSMENT; EXPERT SYSTEMS; FILAMENT WINDING;

LANDING GEAR; MILITARY AIRCRAFT; NONDESTRUCTIVE TESTS; PULTRUSION; THERMOPLASTIC RESINS

Subject Classification: 7524 Composite Materials (1975-)

31/5/3 (Item 3 from file: 108)

1685584 A90-18412

Quantitative evaluation of CFRP void contents using ultrasonic attenuation and velocity

HSU, DAVID K. (Iowa State University of Science and Technology, Ames)

IN: Japan-U.S. Conference on Composite Materials, 4th, Washington, DC, June 27-29, 1988, Proceedings (A90-18351 06-24). Lancaster, PA, Technomic Publishing Co., Inc., 1989, p. 1015-1024. Research supported by the Iowa State University of Science and Technology.

Publication Date: 1989 11 Refs.

Contract No.: W-7405-ENG-82

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA9006

Ultrasonic nondestructive techniques were used to determine void contents in carbon/epoxy and carbon/polyimide composites fabricated from unidirectional and woven preregs. The techniques used were based on immersion mode transmission and pulse-echo measurements of broadband ultrasonic pulses in the composites. In attenuation measurements, the void content exhibits a nearly linear dependence on the rate of increase in attenuation with respect to frequency. The void content of the composites is also found to correlate with changes in the ultrasonic phase velocity in the material. (V.L.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *CARBON FIBER REINFORCED PLASTICS; *LAMINATES; *NONDESTRUCTIVE TESTS; *ULTRASONIC FLAW DETECTION; ELASTIC WAVES; MECHANICAL PROPERTIES; WAVE ATTENUATION; WAVE PROPAGATION

Subject Classification: 7538 Quality Assurance & Reliability (1975-)

31/5/4 (Item 4 from file: 108)

1665541 A89-50074

Lamb-wave monitoring of axial stiffness reduction of laminated composite plates

TANG, B. (Creighton University, Omaha, NE); HENNEKE, E. G., II (Virginia Polytechnic Institute and State University, Blacksburg)

Materials Evaluation (ISSN 0025-5327), vol. 47, Aug. 1989, p. 928-934.

Research supported by the General Electric Co. and Center for Innovative

Technology.

Publication Date: Aug. 1989 26 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: JOURNAL ARTICLE

Documents available from AIAA Technical Library

Journal Announcement: IAA8922

A simple method similar to the acousto-ultrasonic experimental technique was used to generate and detect Lamb waves in laminated composite plates. Dispersion curves of the lowest symmetric and antisymmetric Lamb modes were obtained. The lowest antisymmetric mode was found to be sensitive to damage in composite plates. Stiffness reduction in a (90/90/90/0)s graphite-epoxy laminate and a (0/45/0/45/0/45)s woven graphite-polyimide composite laminate was monitored by the lowest antisymmetric Lamb mode. (Author)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *COMPOSITE STRUCTURES; *LAMB WAVES; *LAMINATES; *PLATES (STRUCTURAL MEMBERS); *STIFFNESS; *ULTRASONIC TESTS; GRAPHITE-EPOXY COMPOSITES; POLYIMIDE RESINS; WAVE PROPAGATION

Subject Classification: 7524 Composite Materials (1975-)

31/5/5 (Item 5 from file: 108)

1636825 A89-30583

Parametric studies of impact testing in laminated and woven architectures

MAJIDI, AZAR P. (Delaware, University, Newark); TASKE, LEO E., II

IN: American Society for Composites, Technical Conference, 3rd, Seattle, WA, Sept. 25-29, 1988, Proceedings (A89-30551 11-24). Lancaster, PA, Technomic Publishing Co., Inc., 1988, p. 374-383. Research supported by the U.S. Army and University of Delaware.

Publication Date: 1988 10 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA8911

The impact behavior of cross-ply laminates, and two- and three-dimensionally woven graphite/PEEK composites have been studied. The parameters examined in these systems during impact testing included weave geometry, fiber volume fraction, and part thickness. The effect of thickness, in the range of 1.7 to 4.7 mm, was studied on cross-ply laminates and two-dimensional (2-D) woven structures. The flexural moduli and the reduced stiffnesses of the respective system were used to determine the dependence of the absorbed impact energy on thickness. The data showed that, similar to the bending stiffness, the impact energy is linearly proportional to the cube of the thickness of the composite. This relationship was used to compare minor thickness variations between two 3-D woven comingled angle interlock structures. The residual strength of the impacted panels was evaluated by cutting the panel into a number of strips and testing in four point flexure. The 3-D woven materials contained the damage to a smaller area than the unidirectional cross-ply and the 2-D woven laminates at 110 J of incident energy. (Author)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *IMPACT TESTS; *LAMINATES; *PEEK; *RESIDUAL STRENGTH; CARBON FIBER REINFORCED PLASTICS; LAY-UP; NONDESTRUCTIVE TESTS

Subject Classification: 7524 Composite Materials (1975-)

31/5/6 (Item 6 from file: 108)

1599939 N88-27250

Balance of X-ray radioscopy application to nondestructive tests of composite materials

BILAN D'UTILISATION DE LA RADIOSCOPIE A RAYONS X APPLIQUEE AU C.N.D. DES MATERIAUX COMPOSITES

LOUBET, DANIEL

Societe Nationale Industrielle Aerospatiale, Saint-Medard-en-Jalles (France).

Publication Date: 1988 10P.

Report No.: SNIAS-881-430-110; ETN-88-92858

Language: French

Country of Origin: France Country of Publication: France

Document Type: REPORT; TRANSLATION

Documents available from AIAA Technical Library

Other Availability: NTIS HC A02/MF A01

Journal Announcement: STAR8821

The results obtained using X ray radioscopy nondestructive control equipment are discussed. Examples referring to composite materials are described. The limitations are discussed. The resolution and the noise problems limit the performance in delamination control, although the application of digital techniques improves results. Remote video radioscopy is very useful for the nondestructive control of filament wound and woven composites, since the real time control of man-operation interactions is of great importance for this kind of product. (ESA)

Descriptors: *COMPOSITE STRUCTURES; *NONDESTRUCTIVE TESTS; *VIDEO DATA; *X RAY INSPECTION; FILAMENT WINDING; IMAGE PROCESSING; RADIOGRAPHY; SPATIAL RESOLUTION; VIDEO SIGNALS

Subject Classification: 7524 Composite Materials (1975-)

31/5/7 (Item 7 from file: 108)

1553208 A88-18226

Advanced composites: The latest developments; Proceedings of the Second Conference, Dearborn, MI, Nov. 18-20, 1986

Conference sponsored by ASM International, Engineering Society of Detroit, SAMPE, et al. Metals Park, OH, ASM International, 1986, 322 p. For individual items see A88-18227 to A88-18246.

Publication Date: 1986

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PROCEEDINGS

Journal Announcement: IAA8805

The present conference on state-of-the-art composites discusses safety factors in composite automobile design, diesel engine pistons with ceramic fiber reinforcement, novel methods in filament winding, flat thermoplastic tape-laying, the damage tolerance of three-dimensionally braided carbon/PEEK composites, stacked composite springs, and thermoplastic vs. thermoset process economics. Also discussed are the fluid mechanics of mold-filling, toughening mechanisms for polymer-matrix composites, SMC surface characterization for adhesion, seam bonding in CRP, high-speed thermoplastic compression molding, long fiber-reinforced thermoplastic composites, metal matrix composites' use as a Be substitute, stress concentration in composite structures, and new applications for dielectric

monitoring and control. (O.C.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *COMPOSITE MATERIALS; *CONFERENCES; *RESEARCH AND DEVELOPMENT; ADHESIVE BONDING; AUTOMOBILES; COMPUTER AIDED DESIGN; FABRICATION; FILAMENT WINDING; JOINING; MANUFACTURING; MATERIALS SCIENCE; METAL MATRIX COMPOSITES; NONDESTRUCTIVE TESTS

Subject Classification: 7524 Composite Materials (1975-)

31/5/8 (Item 8 from file: 108)

1532687 A87-48686

Composites for general aviation aircraft; Proceedings of the General Aviation Aircraft Meeting and Exposition, Wichita, KS, Apr. 28-30, 1987

Meeting and Exposition sponsored by SAE. Warrendale, PA, Society of Automotive Engineers, Inc. (SAE SP-717), 1987, 37 p. For individual items see A87-48687 to A87-48691.

Publication Date: 1987

Report No.: SAE SP-717

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PROCEEDINGS

Journal Announcement: IAA8721

The present conference discusses the certification of bonded primary structure composite airframes for general aviation aircraft, the composite implementation of a lightweight and low cost air-to-air missile control surface, and the state-of-the-art development status of general aviation aircraft structures technologies. Also discussed are the roles that may be played by alternative types of woven reinforcements in advanced composite materials, and the determination of resin-matrix composites' fiber volumes by means of density measurements. (O.C.)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *AIRCRAFT CONSTRUCTION MATERIALS; *COMPOSITE MATERIALS; *CONFERENCES; *GENERAL AVIATION AIRCRAFT; COMPOSITE STRUCTURES; CONTROL

SURFACES; FABRICATION; NONDESTRUCTIVE TESTS; STRUCTURAL RELIABILITY

Subject Classification: 7501 Aeronautics--General (1975-)

31/5/9 (Item 9 from file: 108)

1427338 A86-18574

Thermal-wave nondestructive evaluation of a carbon-epoxy composite using mirage effect

INGLEHART, L. J.; LEPOUTRE, F.; CHARBONNIER, F. (Ecole Supérieure de Physique et de Chimie Industrielles, Paris, France)

Journal of Applied Physics (ISSN 0021-8979), vol. 59, Jan. 1, 1986, p. 234-240. CEA-supported research.

Publication Date: Jan. 1986 23 Refs.

Language: English

Country of Origin: France Country of Publication: United States

Document Type: JOURNAL ARTICLE

Documents available from AIAA Technical Library

Journal Announcement: IAA8606

New results obtained for thermal-wave nondestructive evaluation applied to composite material using the mirage effect are reported. A composite of woven carbon fibers and epoxy consisting of both opaque and transparent parts has been thermally characterized. The thermal diffusivity in the

different regions of the composite has been measured. An anisotropy was found in the thermal diffusivity of the fibers and an effective diffusivity of the epoxy was calculated. From these experimental values, it has been possible to determine the thickness of the epoxy which coats, in many parts, the fibers. Subsurface cuts made perpendicular to the fibers were easily detected. (Author)

Source of Abstract/Subfile: AIAA/TIS

Descriptors: *CARBON FIBER REINFORCED PLASTICS; *EPOXY MATRIX COMPOSITES; *NONDESTRUCTIVE TESTS; *WEAVING; AMPLITUDE DISTRIBUTION ANALYSIS; CRACKS; DEFECTS; DELAMINATING; GRAPHITE-EPOXY COMPOSITES; THERMAL DIFFUSIVITY

Subject Classification: 7538 Quality Assurance & Reliability (1975-)

31/5/10 (Item 1 from file: 8)

02711127 E.I. Monthly No: EI8903019443

Title: Ultrasonic measurements of porosity in woven graphite polyimide composites.

Author: Hsu, David K.

Corporate Source: Iowa State Univ, Ames, IA, USA

Source: Review of Progress in Quantitative Nondestructive Evaluation v 7B 1988 p 1063-1068

Publication Year: 1988

CODEN: RPQEDF ISSN: 0743-0760 ISBN: 0-306-42837-7

Language: English

Document Type: JA; (Journal Article) Treatment: A; (Applications); X; (Experimental); T; (Theoretical)

Journal Announcement: 8903

Abstract: The method of estimating the porosity volume fraction based on the slope of ultrasonic attenuation with respect to frequency was extended to apply to woven composite laminates. Because of the woven structure the voids were mostly localized in pockets of resin and remained roughly spherical. This morphology had a large effect on the constant relating the void volume fraction to the attenuation slope. The method was tested on measurement results derived for a group of graphite polyimide composites. 4 Refs.

Descriptors: *COMPOSITE MATERIALS--*Porosity; PLASTICS LAMINATES; PLASTICS, REINFORCED--Graphite Fibers; NONDESTRUCTIVE EXAMINATION--Ultrasonic Applications; POLYIMIDES; ULTRASONIC WAVES--Attenuation

Identifiers: SCATTERING AMPLITUDES; ULTRASONIC ATTENUATION; ULTRASONIC TESTING; VOID DETECTION; VOLUME FRACTION; WOVEN GRAPHITE POLYIMIDE RESINS

Classification Codes: 415 (Metals, Wood & Other Structural Materials); 753 (Sound Technology & Ultrasonics); 422 (Materials Testing); 941 (Acoustical & Optical Measuring Instruments); 817 (Plastics, Products & Applications)

41 (CONSTRUCTION MATERIALS); 75 (ACOUSTICAL TECHNOLOGY); 42 (MATERIALS PROPERTIES & TESTING); 94 (INSTRUMENTS & MEASUREMENT); 81 (CHEMICAL PROCESS INDUSTRIES)

31/5/11 (Item 1 from file: 4)

03972687 INSPEC Abstract Number: A91123653

Title: Impact properties of three-dimensional braided graphite/epoxy composites

Author(s): Gong, J.C.; Sankar, B.V.

Author Affiliation: Dept. of Mech. Eng., Drexel Univ., Philadelphia, PA, USA

Journal: Journal of Composite Materials vol.25, no.6 p.715-31

Publication Date: June 1991 Country of Publication: USA

CODEN: JCOMBI ISSN: 0021-9983

Language: English Document Type: Journal Paper (JP)

Treatment: Experimental (X)

Abstract: An experimental study of the response and damage of three-dimensional braided graphic/epoxy composite due to sub-perforation velocity impact was carried out in this research. Simply supported square plates were impacted with an instrumented impact pendulum and also a projectile fired by a gas gun. Hemispherical nose impactors of two different diameters. 12.7 mm and 25.4 mm, were used in the pendulum tests. In addition, static flexure tests were performed. Impact damage was assessed using X-radiography, and compression after impact tests. Damages involved in impacted braided panel are matrix cracking in resin pockets, separation of fiber tows, and fiber tow breakage, mostly in fiber bundle crimp areas. A quasi-isotropic laminate was impact tested with pendulum for comparison of impact tolerance between the two composite systems. (13 Refs)

Descriptors: bending; carbon fibre reinforced composites; impact (mechanical); laminates

Identifiers: 3D braided graphite fibre reinforced epoxy composites; sub-perforation velocity impact; pendulum tests; static flexure tests; X-radiography; fiber tow breakage; fiber bundle crimp areas; quasi-isotropic laminate; C

Class Codes: A8140N (Fatigue, embrittlement, and fracture); A8140L (Deformation, plasticity and creep); A6220M (Fatigue, brittleness, fracture, and cracks); A6220F (Deformation and plasticity)

Chemical Indexing:

C ss (Elements - 1)

31/5/12 (Item 2 from file: 4)

03692588 INSPEC Abstract Number: A90112864, B90054300

Title: Analysis of interference patterns in scanning acoustic microscope images of composites

Author(s): Downs, D.A.; El-Shiekh, A.H.; Tucker, P.A.; Russ, J.C.

Author Affiliation: North Carolina State Univ., Raleigh, NC, USA

Journal: Journal of Computer-Assisted Microscopy vol.1, no.2 p. 195-215

Publication Date: June 1989 Country of Publication: USA

CODEN: JCMIEX ISSN: 1040-7286

U.S. Copyright Clearance Center Code: 1040-7286/89/0600-0195\$06.00/0

Language: English Document Type: Journal Paper (JP)

Treatment: Experimental (X)

Abstract: Interference fringes adjacent to fibers intersecting a planar section surface in acoustic photomicrographs of braided graphite/epoxy composites are shown to give quantitative data for the determination of the longitudinal wave speed in the matrix and for describing the orientation of the fibers in the matrix. Often considered an unfortunate aberration of highly resolved acoustic images of composites, the fringe patterns are found to offer a method of determining elastic properties of the composite material, parameters unavailable from traditional light images. (14 Refs)

Descriptors: aberrations; acoustic microscopy; carbon fibre reinforced plastics; composite materials; elastic moduli measurement; nondestructive testing

Identifiers: graphite fiber reinforced epoxy resin composites; interference patterns; scanning acoustic microscope images; planar section surface; acoustic photomicrographs; braided graphite/epoxy composites; longitudinal wave speed; aberration; elastic properties; C

Class Codes: A8170C (Nondestructive testing); A4385 (Acoustical measurements and instrumentation); A4630R (Measurement methods and techniques); B0590 (Materials testing); B7820 (Sonic and ultrasonic applications); B7320Z (Other nonelectric variables)

Chemical Indexing:

C ss (Elements - 1)

31/5/13 (Item 1 from file: 293)

083829 EMA Number: 9105-B2-D-0259

Acoustic Emission During Deformation and Fracture Processes of 3D C/C Composite.

Fen, S ; Bai, S ; Zhu, Z

Academia Sinica

Progress in Acoustic Emission. IV, Kobe, Japan, 14-17 Nov. 1988

p. 765-772

Publ: Japanese Society for Non-Destructive Inspection, Hashimoto Building, 5-4-5, Asakusa-bashi, Taito-ku, Tokyo, Japan, 1989

Journal Announcement: 9105

Document Type: BOOK

Language: ENGLISH

Acoustic emission (AE) behaviors have been studied during the deformation and fracture processes of three-dimensional woven carbon/carbon (3D C/C) composite. The notched specimens were prepared from 3D C/C composite which contained the homogeneous, inhomogeneous and disorder woven structure, respectively. Specimens were subjected to three-point bending-loading and monitored by AE system. The acoustic emission features of 3D C/C and C matrix during tests have been studied. The microscope examinations corresponding to different stages of acoustic emission were also observed. It was discovered that sources of acoustic emissions for 3D C/C came from matrix crazing, fibre splitting, fibre fracture and pull-out. Signals of acoustic emission during the damage processes of 3D C/C mainly resulted from the fibre fracture. The acoustic emission characteristics of 3D C/C were related to the fibre structure and the orientation of the crack. It was found that the quality and the damage degree of 3D C/C could be evaluated by acoustic emission technique. Photomicrographs, Spectra, Graphs. 4 ref.--AA

Descriptors: Carbon-carbon composites-- Nondestructive testing; Crazing; Fiber pull out; Acoustic emission testing; Cracking (fracturing); Splitting

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

31/5/14 (Item 2 from file: 293)

072574 EMA Number: 9010-B2-D-0665

Analysis of Ultrasonic Backscatter for Porosity Characterization in Graphite--Epoxy Composites.

Roberts, R A

Argonne National Laboratory

Review of Progress in Quantitative Nondestructive Evaluation. Vol. 8B, La Jolla, California, USA, 1-5 Aug. 1988

p. 1559-1566

Publ: Plenum Press, 233 Spring Street, New York, New York 10013, USA, 1989

Journal Announcement: 9010

Document Type: BOOK

Language: ENGLISH

Azimuthal-angle backscatter scans, which examine total backscattered energy as a function of porosity, were performed for woven cross-ply composites. Analyses which examined the overall level of backscatter and the angular dependence of backscatter revealed that both the mean value and shape (i.e., peak-to-valley separation) of the backscatter curves were very sensitive to the initial onset of porosity. The observed sensitivity of backscatter curve shape to porosity is believed to be the result of the constraint of pore growth to a near-spherical morphology by the fiber weave. This is in contrast to the lesser sensitivity of backscatter curve shape to porosity previously observed in nonwoven cross-ply composites, in which the pores displayed a cylindrical morphology. Azimuthal-angle scans were also performed in nonwoven cross-ply composites to examine the spectral content of the backscatter with previously developed signal processing. Spectral features were observed which appear to be related to the layered ply structure of the composite, and a sensitivity to the introduction of porosity was observed. A particular spectral minimum, which is believed to be associated with the near-periodic spacing of the 0 deg ply in the ply lay-up was studied in detail. Strong sensitivity to the onset of porosity was observed. Graphs, Spectra. 6 ref.--AA

Descriptors: Graphite-epoxy composites-- Nondestructive testing; Laminates-- Nondestructive testing; Cloth reinforcements; Ultrasonic testing; Backscattering; Sensitivity

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

31/5/15 (Item 3 from file: 293)

066118 EMA Number: 9006-B2-D-0355

Evaluation of Anisotropic Damage in Ceramic--Ceramic (SiC--SiC) Composite by Ultrasonic Method.

Guerjouma, R El; Baste, S

Universite de Bordeaux, CNRS

Ultrasonics International 89, Madrid, Spain, 3-7 July 1989

p. 895-900

Publ: Butterworths, P.O. Box 63, Westbury House, Bury Street, Guildford, Surrey GU2 5BH, UK, 1989

Journal Announcement: 9006

Document Type: BOOK

Language: ENGLISH

During a loading process of 2D woven ceramic--ceramic (SiC--SiC) composite, an immersion device is used to measure, according to the propagation direction, velocities and attenuations variations of ultrasonic waves (longitudinal and shear modes) as function of applied stress. The SiC--SiC, which is a brittle--brittle composite exhibits non linear anisotropic mechanical behavior. The non linearities, due to the matrix microcracking, appear macroscopically as a decrease of elastic stiffness. Through an optimization procedure, experimental values of velocities (slowness curves as function of stress) lead to the calculation of several elastic constants and their evolution vs. stress. This ultrasonic device allows one to characterize the SiC--SiC elastic non linear behavior

(elasticity--anisotropic damage coupling) during the uniaxial tensile test.

Graphs. 11 ref.--AA

Descriptors: Silicon carbide-- Composite materials; Ceramic matrix composites-- Nondestructive testing; Ultrasonic testing; Elastic constants; Stiffness; Damage

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

31/5/16 (Item 4 from file: 293)

044358 EMA Number: 8903-B2-P-0160

Electromagnetic Imaging for Reconstruction of Flaws in Advanced Composites.

Treece, J C ; Roberts, T M ; Schunk, S D

Sabbagh Associates

Review of Progress in Quantitative Nondestructive Examination. Volume 7A, Williamsburg, Virginia, USA, 22-26 June 1987

p. 349-356

Publ: Plenum Press, 233 Spring Street, New York, New York 10013, USA, 1988

Journal Announcement: 8903

Document Type: BOOK

Language: ENGLISH

The conductivity of advanced composite materials can be used as a way of determining the condition of an article. Eddy currents can be measured and if a scanning phase is used a 3-D plot can be presented. A woven graphite-epoxy composite and an anisotropic laminate have been used to demonstrate the induced EMF and holes have been drilled into the specimens to further illustrate the effects of flaws. 8 ref.--D.M.

Descriptors: Laminates-- Nondestructive testing; Graphite-epoxy composites-- Nondestructive testing; Eddy current testing; Flaw detection

Section Headings: B2 Testing & Quality Control

Subfile: P Polymers

31/5/17 (Item 5 from file: 293)

044147 EMA Number: 8902-F2-D-0677

Use of Optical Fibre for Damage and Strain Detection in Composite Materials.

Waite, S R ; Tatam, R P ; Jackson, A

City University (London), University of Kent

Composites, (6), p. 435-442 ISSN: 0010-4361

Publication Date: Mar. 1988

1988

Journal Announcement: 8902

Document Type: ARTICLE

Language: ENGLISH

A polarization maintaining optical fibre was embedded in a woven glass epoxy composite three point bend specimen and loaded to failure to determine the effectiveness of such fibre as a strain gauge and damage indicator. Various fibre surface treatments were investigated and the validity of assuming structural strain continuity for those fibres was assessed by comparing experimental data with the structural strain level. Results indicate that silane treated and buffered fibre can reasonably be considered to have adopted the structural strain, however care in treatment is necessary. 14 ref.--AA

Descriptors: Glass fiber reinforced plastics-- Nondestructive testing;
Epoxy resins-- Composite materials; Optical fibers; Damage; Strain; Failure
Section Headings: F2 Electrical, Electronic, & Optical
Subfile: D Composites

31/5/18 (Item 6 from file: 293)

022750 EMA Number: 8710-B2-D-0481

Fatigue Life Prediction of Glass Fibre-Reinforced Plastics Using the
Acousto-Ultrasonic Technique.

Srivastava, V K ; Prakash, R

Int. J. Fatigue, 9, (3), p. 175-178 ISSN: 0142-1123

Publication Date: July 1987

1987

Journal Announcement: 8710

Document Type: ARTICLE

Language: ENGLISH

Composite materials possess the characteristics of high stiffness and high fatigue strength which are desirable for advanced aircraft components. However, the fatigue behaviour of such materials depends upon a variety of factors (such as fibre volume fraction, percentage of voids and lay-up order), the effects of which are difficult to establish individually, so that a wholistic approach is the only satisfactory solution. A nondestructive evaluation technique, which is a combination of acoustic emission and ultrasonics, for the evaluation of the fatigue life of a cross-ply (0/90 deg C) E glass fibre woven mat-reinforced CY-205 epoxy composite is presented. The results show that the fatigue life can be determined from the parameter known as the stress wave factor with the required degree of confidence. 11 ref.--AA

Descriptors: Epoxy resins-- Composite materials; Glass fiber reinforced plastics-- Nondestructive testing; Laminates-- Nondestructive testing; Fatigue tests; Acoustic emission; Ultrasonic testing; Aircraft components-- Materials selection

Trade Name/Material Index(Identifier): CY-205-- PAF

Section Headings: B2 Testing & Quality Control

Subfile: D Composites

31/5/19 (Item 1 from file: 6)

1347132 NTIS Accession Number: N88-27250/5/XAB

Bilan d'Utilisation de la Radioscopie a Rayons X Appliquee au C.N.D. Des
Materiaux Composites (Balance of X-ray Radioscopy Application to
Nondestructive Tests of Composite Materials)

Loubet, D.

Societe Nationale Industrielle Aerospatiale, Saint-Medard-en-Jalles
(France).

Corp. Source Codes: 072439000; SQ454255

Sponsor: National Aeronautics and Space Administration, Washington, DC.

Report No.: SNIAS-881-430-110; ETN-88-92858

1988 10p

Languages: French

Journal Announcement: GRAI8824; STAR2621

Text in French.

NTIS Prices: PC A02/MF A01

Country of Publication: France

The results obtained using X ray radioscopy nondestructive control

equipment are discussed. Examples referring to composite materials are described. The limitations are discussed. The resolution and the noise problems limit the performance in delamination control, although the application of digital techniques improves results. Remote video radioscopy is very useful for the nondestructive control of filament wound and woven composites, since the real time control of man-operation interactions is of great importance for this kind of product.

Descriptors: *Composite structures; *Nondestructive tests; *Video data; *X ray inspection; Filament winding; Image processing; Radiography; Spatial resolution; Video signals

Identifiers: *Foreign technology; NTISNASAT

Section Headings: 71F (Materials Sciences--Composite Materials); 41G (Manufacturing Technology--Quality Control and Reliability); 94J (Industrial and Mechanical Engineering--Nondestructive Testing)

NDE/NDT OF COMPOSITE MATERIALS IN GENERAL

16/7/1 (Item 1 from file: 108)

1803751 A91-55485

Nondestructive evaluation of damage development in composite materials
DANIEL, ISAAC M.; WOOH, SHI-CHANG; LEE, JAE-WON (Northwestern University, Evanston, IL)

IN: Elastic waves and ultrasonic nondestructive evaluation; Proceedings of the IUTAM Symposium on Elastic Wave Propagation and Ultrasonic Evaluation, Boulder, CO, July 30-Aug. 3, 1989 (A91-55476 24-71). Amsterdam and New York, North-Holland, 1990, p. 183-189. Research sponsored by U.S. Navy.

Publication Date: 1990 13 Refs.

Language: English

Country of Origin: United States Country of Publication: Netherlands

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA9124

Nondestructive methods were developed and applied to the characterization of progressive damage in crossply composite laminates subjected to monotonic and cyclic tensile loading. The objective of the study was to study damage evolution, characterize the damage and correlate the damage/NDE output with stiffness. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/2 (Item 2 from file: 108)

1792594 A91-48229

Image processing of composite materials using ultrasonic nondestructive evaluation data

BLAKE, ROBERT A., JR. (Alcoa Technical Center, Alcoa Center, PA)

IN: Non-destructive testing of fibre-reinforced plastics composites. Vol. 2 (A91-48226 20-38). London and New York, Elsevier Applied Science, 1990, p. 161-200.

Publication Date: 1990

Language: English

Country of Origin: United States Country of Publication: United Kingdom

Document Type: ANALYTIC OF COLLECTED WORK

Documents available from AIAA Technical Library

Journal Announcement: IAA9120

The use of image enhancement is discussed with respect to the interpretation of ultrasonic nondestructive evaluation (NDE) C-scans. Image analysis and signal processing are employed after initial inspection to classify the anomalies by location type and thereby determine its potential effect on the composite structure. The effects of the defects are determined based on the states of stress in the components and suitable model of the flaw criticality or a failure model. Imaging methods, image histogram evaluation techniques, kernel multiplications, and 2D Fourier analysis are discussed with respect to image processing. The image enhancement techniques are found to facilitate the detection and recognition of structural anomalies which are not apparent when the ultrasonic C-scan is initially formed. Signal-pattern recognition is found to permit the classification of material anomalies by type and location, thereby improving evaluations of structural integrity. (C.C.S.)

Source of Abstract/Subfile: AIAA/TIS

16/7/3 (Item 3 from file: 108)

1755958 A91-23718

Anisotropic wave propagation and its applications to NDE of composite materials

WU, T.-T. (National Taiwan University, Taipei, Republic of China); HO, Z.-H.

Experimental Mechanics (ISSN 0014-4851), vol. 30, Dec. 1990, p. 313-318.

Publication Date: Dec. 1990 9 Refs.

Language: English

Country of Origin: Taiwan Country of Publication: United States

Document Type: JOURNAL ARTICLE

Documents available from AIAA Technical Library

Journal Announcement: IAA9108

This paper utilized anisotropic wave propagation theory to measure the elastic constants of a unidirectional fiber-reinforced composite specimen. For plane waves propagating in the composite specimen, the deviation of the propagational directions between the energy and phase velocities were measured. It is found that in such a sample, the deviations may be as large as 60 degrees. The measured energy velocities were transformed to the phase velocities of the plane waves by employing a numerical scheme. It is demonstrated that the elastic constants of a unidirectional fiber-reinforced composite can be determined by conducting ultrasonic experiments in two principal symmetry planes. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/4 (Item 4 from file: 108)

1748236 A91-18570

The utility of guided waves in the ultrasonic NDE of composite materials

ROSE, J. L.; BALASUBRAMANIAM, K.; DITRI, J. (Drexel University, Philadelphia, PA); PILARSKI, A. (Polska Akademia Nauk, Warsaw, Poland)

IN: Non-destructive testing; Proceedings of the Twelfth World Conference, Amsterdam, Netherlands, Apr. 23-28, 1989. Volume 2 (A91-18526 05-38). Amsterdam, Netherlands and New York, Elsevier Science Publishers, 1989, p. 1567-1572. Research supported by the U.S. Navy and U.S. Army.

Publication Date: 1989 12 Refs.

Language: English

Country of Origin: United States Country of Publication: Netherlands

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA9105

This paper presents an overview, supported by several theoretical and experimental results, of some recent guided wave research applied to composite materials. Graphite-epoxy fiber reinforced laminated composite materials were chosen here and the focus of the study was limited to hexagonal and orthogonal symmetries of material anisotropic configurations.

The types of guided waves considered were the Plate modes, Surface waves and the Sub-surface waves, generated by an obliquely incident ultrasonic source. Aside from the evaluation of localized gross defects such as delaminations, voids etc., quantitative estimations of the degree of porosity, fiber volume fraction and hydro-thermal degradation was successfully attempted. Experimental results are used to demonstrate the utility of guided waves in the NDE of composite materials. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/5 (Item 5 from file: 108)

1743302 N91-11882

Nuclear magnetic resonance nondestructive evaluation of composite materials

Final Technical Report, 19 Sep. 1987 - 19 Jun. 1989

LIND, ARTHUR C.; FRY, CHARLES G.

McDonnell-Douglas Research Labs., Saint Louis, MO.

Publication Date: Apr. 1990 80P.

Report No.: AD-A225268; MDC-QA035; WRDC-TR-89-4117

Contract No.: F33615-87-C-5247

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: REPORT

Documents available from AIAA Technical Library

Other Availability: NTIS HC/MF A05

Journal Announcement: STAR9103

Nuclear magnetic resonance (NMR) was studied for use in the nondestructive evaluation of composite materials, with particular emphasis on NMR imaging. NMR parameters of potential use for generating images showing high contrast between acceptable and unacceptable regions of composites were measured for typical organic matrix materials. The attenuating effects of carbon fibers were measured and relationships were developed to compute the conditions necessary to obtain images of carbon fiber composites. NMR images of aerospace composites containing poly(aryl-ether-ether-ketone) (PEEK) and epoxy resins were obtained using solid state C-13 techniques. The contrast mechanism used for these images was the composites. NMR images of hydrogen in PEEK were also obtained using multiple pulse techniques to reduce dipolar broadening. Selective pulses were used to obtain images of the spatial variations in the crystalline content of PEEK. The results of these experiments were used to assess the feasibility of using NMR for nondestructive evaluation of composite materials. (GRA)

Source of Abstract/Subfile: DTIC

16/7/6 (Item 6 from file: 108)

1693649 A90-23954

Eddy current nondestructive testing of graphite composite materials

VALLEAU, A. R. (T. A. O. Gross, Inc., Lincoln, MA)

Materials Evaluation (ISSN 0025-5327), vol. 48, Feb. 1990, p. 230-239.

Publication Date: Feb. 1990 7 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: JOURNAL ARTICLE

Documents available from AIAA Technical Library

Journal Announcement: IAA9009

Several factors that commonly occur in carbon-fiber-reinforced composites and that affect the impedance of an eddy current probe in NDT have been characterized on the complex impedance plane. At eddy current instrument that stimulates target material at several frequencies, measures the impedance of the probe, compares the impedances to reference material, and determines the condition of the target material has been developed and demonstrated. The instrument can find a number of conditions commonly found

by eddy currents and can be programmed to find others, such as conductive and nonconductive plating thicknesses and inclusions of material with a ferrous content. The instrument can be used with conductive materials in addition to carbon-fiber-reinforced composites. (C.D.)

Source of Abstract/Subfile: AIAA/TIS

16/7/7 (Item 7 from file: 108)

1668019 A89-51699

Ultrasonic nondestructive evaluation of fibre-reinforced composite materials - A review

KINRA, VIKRAM K.; DAYAL, VINAY (Texas A & M University, College Station)

IN: Composite materials and structures (A89-51691 23-24). Bangalore, Indian Academy of Sciences, 1988, p. 147-160.

Publication Date: 1988 52 Refs.

Language: English

Country of Origin: United States Country of Publication: India

Document Type: ANALYTIC OF COLLECTED WORK

Documents available from AIAA Technical Library

Journal Announcement: IAA8923

This paper reviews various ultrasonic nondestructive evaluation techniques applicable to fiber-reinforced composites. The techniques are briefly described and key references are cited. Methods to evaluate the reduced stiffness of composites due to micro-damage are described. Results show that for composites through-the-thickness attenuation increases and stiffness do not change due to transverse cracks, but in-plane stiffness and attenuation changes are substantial and can be measured by the Lamb wave techniques. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/8 (Item 8 from file: 108)

1666259 A89-50792

Nondestructive evaluation of interfacial damages in composite materials

GAO, ZHANJUN; MURA, T. (Northwestern University, Evanston, IL)

International Journal of Solids and Structures (ISSN 0020-7683), vol. 25, no. 8, 1989, p. 901-916. Research supported by Rockwell International Corp.

Publication Date: 1989 13 Refs.

Contract No.: DAAL03-88-C-0027

Language: English

Country of Origin: United States Country of Publication: United Kingdom

Document Type: JOURNAL ARTICLE

Documents available from AIAA Technical Library

Journal Announcement: IAA8922

By using the residual surface displacement data, the microscopic damages in terms of Somigliano's dislocations in composites near the interface caused by a series of unknown loading are examined. The goal of this research is to monitor the processes of the damage evolution near the interface and to relate this microscopic damage to the degradation of the macroscopic mechanical properties of the materials. The problem is an inverse problem, therefore, the uniqueness and stability must be considered. It is proved that the residual fields and all the characteristic quantities along the interface, such as displacement jumps, are uniquely determined by the residual surface displacements. It follows that the traction free parts of the interface correspond to cracks, the normal displacement jumps indicate debonding and the tangential

displacement jumps measure the interfacial sliding. The numerical calculations are stabilized. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/9 (Item 9 from file: 108)

1646168 A89-36571

Nondestructive evaluation/characterization of composite materials and structures using the acousto-ultrasonic techniques

DOS REIS, H. L. M. (Illinois, University, Urbana); VARY, A. (NASA, Lewis Research Center, Cleveland, OH)

Illinois Univ., Urbana.

IN: SEM Fall Conference, Indianapolis, IN, Nov. 7, 8, 1988, Proceedings (A89-36568 15-38). Bethel, CT, Society for Experimental Mechanics, Inc., 1988, p. 25-32.

Publication Date: 1988 30 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA8915

This paper introduces the nature and the underlying rationale of the acousto-ultrasonic stress wave factor technique and some of its applications to composite materials and structures. Furthermore, two examples of successful application of the acousto-ultrasonic technique are presented in detail. In the first example, the acousto-ultrasonic technique is used to evaluate the adhesive bond strength between rubber layers and steel plates, and in the second example the technique is used to monitor progressive damage in wire rope. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/10 (Item 10 from file: 108)

1636840 A89-30598

Engineering tomography - A quantitative NDE technique for composite materials

STOLLER, H. M.; CROSE, J. G.; PFEIFER, W. H. (PDA Engineering, Costa Mesa, CA)

IN: American Society for Composites, Technical Conference, 3rd, Seattle, WA, Sept. 25-29, 1988, Proceedings (A89-30551 11-24). Lancaster, PA, Technomic Publishing Co., Inc., 1988, p. 537-547.

Publication Date: 1988 5 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA8911

Measurements and numerical techniques involved in the engineering tomography (ET) methodology, which combines tomographic inspection techniques with finite element analysis methods, are discussed. The results of early ET studies, which examined the ability of the X-ray computed tomography to measure density and density variations in composite materials are reviewed, and the results of recent investigations on the relationships between density variations and the material properties of representative composite materials are presented. (I.S.)

Source of Abstract/Subfile: AIAA/TIS

16/7/11 (Item 11 from file: 108)

1630352 A89-25799

An ultrasonic NDE surface wave feature matrix technique for composite materials

ROSE, J. L.; PILARSKI, A. (Philadelphia, University, PA)

IN: Wave propagation in structural composites; Proceedings of the Joint ASME/SES Applied Mechanics and Engineering Sciences Conference, Berkeley, CA, June 20-22, 1988 (A89-25790 09-39). New York, American Society of Mechanical Engineers, 1988, p. 117-131. Research sponsored by the U.S. Navy.

Publication Date: 1988 27 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA8909

Numerical methods for interpreting ultrasonic NDE data on advanced high-strength high-modulus composites are developed and demonstrated. A feature matrix containing stiffness coefficients and other basic anisotropic-elasticity parameters is introduced, and the ways in which such matrices can be generated from computations of material, geometrical, and elastic constants are explored using an inverse surface-wave-velocity approach. Numerical results for a unidirectional CFRP laminate are presented in tables and graphs and discussed in detail; good agreement with experimental data is obtained. (T.K.)

Source of Abstract/Subfile: AIAA/TIS

16/7/12 (Item 12 from file: 108)

1584913 A88-40291

Nondestructive evaluation of composite material using the Stress Pattern Analysis by Thermal Emissions technique

COX, B. N.; PETTIT, D. E. (Lockheed-California Kelly Johnson Research and Development Center, Burbank)

IN: 1987 SEM Spring Conference on Experimental Mechanics, Houston, TX, June 14-19, 1987, Proceedings (A88-40251 16-39). Bethel, CT, Society for Experimental Mechanics, Inc., 1987, p. 545-552.

Publication Date: 1987 9 Refs.

Language: English

Country of Origin: United States Country of Publication: United States

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA8816

Increased use of composite structural materials for aircraft necessitates further development of methods for composite nondestructive evaluation (NDE). Results of experimental work involving the thermographic characterization of composite material defects are presented using the Stress Pattern Analysis by Thermal Emission (SPATE) system. Preliminary studies of the effect of ply orientation and surface coatings on the signal strength and noise level are presented. The sensitivity of the technique to detect Kapton inserts in the laminates and to detect impact damage in thick laminates is examined. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/13 (Item 13 from file: 108)

1579764 A88-36881

Use of a medical tomodensitometer in nondestructive testing of composite materials

THIERY, CHRISTIAN (CEA, Bruyeres le Chatel, France)

IN: International Conference on Composite Materials, 6th, and European Conference on Composite Materials, 2nd, London, England, July 20-24, 1987, Proceedings. Volume 1 (A88-36851 14-24). London and New York, Elsevier Applied Science, 1987, p. 1.369-1.374.

Publication Date: 1987

Language: English

Country of Origin: France Country of Publication: United Kingdom

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA8814

This paper presents the results of research on fitting and using a medical scanner to control composite materials by examining the rate of component changes, porosity, and density and its fluctuations. Scanning also allows the detection of defects such as local porosity, delamination, and inclusion and studies on the evolution of materials submitted to constraint (such as humidity, heat, and compression). (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/14 (Item 14 from file: 108)

1579760 A88-36877

Nondestructive evaluation of composite materials using a Raman optomechanical strain gauge

ROBINSON, I. M.; YOUNG, R. J. (University of Manchester Institute of Science and Technology, England)

IN: International Conference on Composite Materials, 6th, and European Conference on Composite Materials, 2nd, London, England, July 20-24, 1987, Proceedings. Volume 1 (A88-36851 14-24). London and New York, Elsevier Applied Science, 1987, p. 1.333-1.340.

Publication Date: 1987 10 Refs.

Language: English

Country of Origin: United Kingdom Country of Publication: United Kingdom

Document Type: CONFERENCE PAPER

Documents available from AIAA Technical Library

Journal Announcement: IAA8814

An optomechanical strain gauge has been developed which can be used to study the internal strain in composite specimens. To illustrate the technique model composites have been prepared consisting of a polydiacetylene fiber in an epoxy resin matrix. In some specimens the matrix was reinforced by glass fibers while in other specimens blunt cracks were cut into the edge of the matrix. Uniaxial stress was applied to the specimens and the strain at all points along the polydiacetylene fiber measured using Raman spectroscopy. The critical length of the fibers could be measured directly; in unreinforced specimens this length was in good agreement with the predictions of shear-lag theories. In the glass reinforced specimens the critical length decreased with increasing fiber volume fraction. In the cracked specimens it was possible to observe considerable strain multiplication ahead of the crack tip. (Author)

Source of Abstract/Subfile: AIAA/TIS

16/7/15 (Item 1 from file: 8)

03319444 E.I. Monthly No: EIM9110-050888

Title: Ultrasonic NDE for composite materials using embedded fiber-optic interferometric sensors.

Author: Liu, Kexing; Ferguson, Suzanne M.; Davis, Andrew; McEwen, Keith; Measures, Raymond M.

Corporate Source: Univ of Toronto Inst for Aerospace Studies, Downsview, Ont, Can

Conference Title: First Canadian-American Eastern Regional Conference on Applications of Optical Engineering

Conference Location: Rochester, NY, USA Conference Date: 1990 Oct 4-5

Sponsor: SPIE, Western New York Chapter; SPIE

E.I. Conference No.: 14893

Source: CAN-AM Eastern '90 Proceedings of SPIE - The International Society for Optical Engineering v 1398. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA. p 206-212

Publication Year: 1991

CODEN: PSISDG ISSN: 0277-786X

Language: English

Document Type: PA; (Conference Paper) Treatment: T; (Theoretical); X; (Experimental)

Journal Announcement: 9110

Abstract: An interferometric fiber optic sensor using ordinary single-mode fibers is developed to detect elastic strain waves for nondestructive evaluation of composite materials. This fiber sensor has been embedded in both graphite/epoxy and Kevlar/epoxy composite specimens. Applications of the sensor for detection of acoustic emission and laser generated ultrasound are presented. Limitations of the sensor are also discussed. (Author abstract) 19 Refs.

16/7/16 (Item 2 from file: 8)

03097019 E.I. Monthly No: EI9108089951

Title: Trends in the development of methods of nondestructive testing of composite materials.

Author: Matis, I. G.

Corporate Source: Inst of Polymer Mechanics, Acad of Sciences of the Latvian SSR, Riga, USSR

Source: Mechanics of Composite Materials (English translation of Mekhanika Kompozitnykh Materialov) v 25 n 3 Nov 1989 p 368-375

Publication Year: 1989

CODEN: MCMAD7 ISSN: 0191-5665

Language: English

Document Type: JA; (Journal Article) Treatment: G; (General Review); A; (Applications)

Journal Announcement: 9108

Abstract: In this review which is based on the materials published abroad in recent years, we examine the trends in the development of the methods and means of nondestructive inspection (NI) of the quality of composite materials (CM). The main direction in the development of the methods and means of NI is the development of means of obtaining information on the physical characteristics for the entire volume of the inspected object; the development of the so-called 'intellectual' measuring systems; the use, for NI purposes, of new physical phenomena and improvement of the existing

principles and inspection methods: use of the means of computing techniques for processing large sets of information, preparation of complicated measurement algorithms, the development of expert systems; the development of new designs of measuring transducers, especially of the matrix type. 19 Refs.

16/7/17 (Item 3 from file: 8)

02962594 E.I. Monthly No: EI9010114292

Title: Enhancement techniques for ultrasonic nondestructive evaluation of composite materials.

Author: Wooh, S. C.; Daniel, I. M.

Corporate Source: Northwestern Univ, Evanston, IL, USA

Source: Journal of Engineering Materials and Technology, Transactions of the ASME v 112 n 2 Apr 1990 p 175-182

Publication Year: 1990

CODEN: JEMTA8 ISSN: 0094-4289

Language: English

Document Type: JA; (Journal Article) Treatment: A; (Applications); X; (Experimental)

Journal Announcement: 9010

Abstract: Conventional ultrasonic C-scanning sometimes produces distorted and degraded images due to a variety of reasons, including surface roughness, beam dispersion, extraneous noise and imperfect fidelity of the total acquisition system. Enhancement techniques, using computer data acquisition and processing, can be used to enhance and restore the image. Enhancement techniques described include contrast stretching and median filtering, histogram equalization, thresholding, dynamic thresholding, thresholding depending on boundary characteristics, one-dimensional segmentation and intensity scans with hidden line removal. These enhancement techniques were applied and illustrated for five different types of damage in graphite/epoxy composite materials. (Edited author abstract) 6 Refs.

16/7/18 (Item 4 from file: 8)

02936299 E.I. Monthly No: EI9008089369

Title: Nondestructive evaluation of composite materials.

Author: Clarke, Barrie

Corporate Source: Royal Aerospace Establishment, Farnborough, Engl

Source: Metals and Materials (Institute of Metals) v 6 n 3 Mar 1990 p 135-139

Publication Year: 1990

CODEN: MMIMEQ ISSN: 0266-7185

Language: English

Document Type: JA; (Journal Article) Treatment: G; (General Review)

Journal Announcement: 9008

Abstract: A major advantage of composite materials is their ability to be tailored to a particular application, but therein lies a problem. Even using carefully specified fibre and matrix materials, components can still exhibit widely different lay-ups, thicknesses and volume fractions, so the same feature may be a serious defect in one component and acceptable in another. This article considers the significance of defects in composite materials and structures, and outlines the nondestructive testing techniques available for their assessment. 9 Refs.

16/7/19 (Item 5 from file: 8)

02762308 E.I. Monthly No: EI8907059203

Title: Nondestructive testing of composite materials.

Author: Girshovich, S.

Corporate Source: Israel Aircraft Industry, Isr

Conference Title: Papers from the First Danish-Israeli Symposium on Nondestructive Evaluation

Conference Location: Lyngby, Den Conference Date: 1988 Jun 27-Jul 1

Sponsor: Danish Ministry of Education, Den; Danish Technical Research Council, Den; Otto Monsted Foundation; Fabricant Mads Clausens Foundation; Ideal-Line A/S; et al

E.I. Conference No.: 12066

Source: NDT International v 21 n 6 Dec 1988. p 457

Publication Year: 1988

CODEN: NDITDS ISSN: 0308-9126

Language: English

Document Type: JA; (Journal Article) Treatment: X; (Experimental)

Journal Announcement: 8907

Abstract: A variety of non-destructive testing techniques are being used at IAI for evaluating the integrity of composite materials and structures. The most extensively used NDT method is ultrasonics, which has been found to be especially suited for detecting delaminations and other discontinuities in laminates and bondlines. For detection of flaws in the radius areas of U-channel spars and in the cross-sections of J, T and I integral ribs, microfocus X-radiography was carried out. In this technique real-time imaging was found to be the most useful method. In order to improve the quality of the real-time image computed image processing was applied. Holographic interferometry was applied for tests of bonded structures. Good results were obtained using heating-cooling excitation. Experimental results obtained on elements of aircraft structure are described and the capabilities and limitations of different NDT methods are discussed. (Edited author abstract)

16/7/20 (Item 6 from file: 8)

02711040 E.I. Monthly No: EI8903019425

Title: Acoustographic nondestructive evaluation of composite materials.

Author: Daniel, I. M.; Wooh, S. C.; Sandhu, J. S.; Hamidzada, W. A.

Corporate Source: Northwestern Univ, Evanston, IL, USA

Source: Review of Progress in Quantitative Nondestructive Evaluation v 7A 1988 p 325-332

Publication Year: 1988

CODEN: RPQEDF ISSN: 0743-0760 ISBN: 0-306-42837-7

Language: English

Document Type: JA; (Journal Article) Treatment: A; (Applications); X; (Experimental)

Journal Announcement: 8903

Abstract: Acoustography, analogous to radiography and photography and developed by Raj Technology, is a process of producing images with acoustic waves on an acoustically sensitive liquid crystal display. Its application to the nondestructive evaluation of composite materials was investigated. Graphite/epoxy specimens of various thickness and layups and containing various flaw types were used. The flaw types included Kapton and Mylar inclusions, porosity, and impact and fatigue damage. Sensitivity losses for the acousto-optical display and the piezoelectric detector as a function of

the ultrasonic incidence angle were determined. Specimen orientation with respect to the insonifying beam was not a critical factor in sensitivity. 8 Refs.

16/7/21 (Item 7 from file: 8)

02693623 E.I. Monthly No: EI8901004554

Title: Recent European work on the NDT of composite materials.

Author: Reynolds, W. N.

Corporate Source: AERE, Oxford, Engl

Source: Materials & Design v 9 n 4 Jul-Aug 1988 p 183-191

Publication Year: 1988

CODEN: MADSD2 ISSN: 0264-1275

Language: English

Treatment: A; (Applications)

Journal Announcement: 8901

Abstract: Various nondestructive techniques and applications to the testing of composite materials are discussed. Among these techniques are ultrasonic methods, acoustic emission testing, X-ray radiography, Vibrational methods, optical techniques, electrical, electromagnetic, thermal, and infrared methods. The composite materials covered include fiber-reinforced plastics and metal matrix composites. 88 refs.

16/7/22 (Item 8 from file: 8)

02678701 E.I. Monthly No: EIM8811-058984

Title: HIGH RANGE RESOLUTION ULTRASONIC C SCAN FOR NONDESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS. .

Author: Zapp, R.; Ho, B.; Li, L.

Corporate Source: Michigan State Univ, East Lansing, MI, USA

Conference Title: International Symposium on Pattern Recognition and Acoustical Imaging.

Conference Location: Newport Beach, CA, USA Conference Date: 1987 Feb 4-6

Sponsor: SPIE, Bellingham, WA, USA; Int Assoc for Pattern Recognition; Acoustical Soc of America, Orange County Chapter, CA, USA; IEEE, Computer Soc, Los Alamitos, CA, USA; IEEE, Ultrasonics, Ferroelectronics and Frequency Control Soc, USA; et al

E.I. Conference No.: 11642

Source: Proceedings of SPIE - The International Society for Optical Engineering v 768. Publ by SPIE, Bellingham, WA, USA p 301-306

Publication Year: 1987

CODEN: PSISDG ISSN: 0277-786X ISBN: 0-89252-803-6

Language: English

Document Type: PA; (Conference Paper)

Journal Announcement: 8811

Abstract: A low cost high range resolution ultrasonic imaging system has been developed to nondestructively evaluate composite material as well as biological tissue and agricultural products. The system, which is capable of dual displays, B and C scans, utilizes high frequency sampling and phase processing of the r. f. signal in order to achieve range resolutions of . 5 mm and range accuracies of . 1 mm. A pseudorandom sequence signal processing scheme is under development to enhance the signal-to-noise ratio for low level signals. (Author abstract)

16/7/23 (Item 9 from file: 8)

02628319 E.I. Monthly No: EIM8808-045499

Title: APPLICATIONS OF DIGITAL IMAGE ENHANCEMENT TECHNIQUES TO THE ULTRASONIC NDE OF COMPOSITE MATERIALS.

Author: Frock, Brian G.; Martin, Richard W.

Corporate Source: Univ of Dayton, Dayton, OH, USA

Conference Title: Acoustical Imaging, Proceedings.

Conference Location: Halifax, NS, Can Conference Date: 1986 Jul 14-16

E.I. Conference No.: 11462

Source: Acoustical Imaging: Proceedings of the International Symposium v

15. Publ by Plenum Press, New York, NY, USA & London, Engl p 461-469

Publication Year: 1987

CODEN: ACIGD9 ISSN: 0270-5117 ISBN: 0-306-42565-3

Language: English

Document Type: PA; (Conference Paper)

Journal Announcement: 8808

Abstract: Results of the applications of local and global digital image enhancement techniques to ultrasonic C-scan images of damaged graphite/epoxy composites are presented. The original unenhanced images were generated by using focused ultrasonic transducers with center frequencies between 3.5 and 25 MHz. Small defects were often difficult to detect in the unenhanced images because the relatively small signal amplitude changes resulting from the defects were obscured by the larger signal amplitude changes caused by variations in: (1) surface roughness, (2) material attenuation, and (3) material morphology. Results given in this paper indicate that those enhancement techniques which emphasize the higher spatial frequencies at the expense of the lower spatial frequencies and those techniques which operate on local pixel regions can often remove enough of the undesirable variations to make small defects visible in the enhanced images. (Author abstract) 15 refs.

16/7/24 (Item 10 from file: 8)

02358507 E.I. Monthly No: EIM8712-085979

Title: THERMOGRAPHY - AN NDE METHOD FOR DAMAGE INVESTIGATION IN COMPOSITE MATERIALS.

Author: Henneke, Edmund G. II

Corporate Source: Virginia Polytechnic Inst & State Univ, Blacksburg, VA, USA

Conference Title: Welding, Failure Analysis, and Metallography, Proceedings of the Eighteenth Annual Technical Meeting of the International Metallographic Society.

Conference Location: Denver, CO, USA Conference Date: 1985 Jul 21-24

Sponsor: ASM, Metals Park, OH, USA; Int Metallographic Soc, Columbus, OH, USA

E.I. Conference No.: 10466

Source: Microstructural Science v 14. Publ by ASM, Metals Park, OH, USA p 521-537

Publication Year: 1987

CODEN: MSSCDJ ISSN: 0361-1213 ISBN: 0-87170-237-1

Language: English

Document Type: PA; (Conference Paper)

Journal Announcement: 8712

Abstract: Thermography refers to the mapping of isothermal contour lines on the surface of an examined test object. Discontinuities in the material or differences in thermal conductivities cause gradients in the isothermal

contours that can be detected by any of various thermographic techniques. This paper reviews those thermographic techniques which have been found to be especially useful for the detection of damage in composite materials. Both passive and active techniques are covered. Passive thermographic techniques are those which develop heat patterns via external heat applied to the test object. Active techniques are those which develop heat patterns via the internal transformation of other forms of energy into heat. In the latter case, vibrothermography has received some attention in the literature and is discussed in some deWZ6. %P}:hor abstract) 15 refs.

16/7/25 (Item 1 from file: 6)

1482376 NTIS Accession Number: N90-22677/0/XAB

Cnd et Cmc a l'Aerospatiale (Nondestructive Testing (NDT); Ceramic Matrix Composite Materials (CMCM))

Albugues, F.

Aerospatiale, Paris (France).

Corp. Source Codes: 000004000; AG943451

Sponsor: National Aeronautics and Space Administration, Washington, DC.

Report No.: REPT-892-430-123; ETN-90-96654

Feb 89 4p

Languages: French

Journal Announcement: GRAI9022; STAR2816

Text in French.

NTIS Prices: PC A01/MF A01

Country of Publication: France

The difficulties involved in producing high quality ceramic matrix composite materials are described. The use of nondestructive testing techniques to help in the optimization of ceramic matrix composite materials is described. A better understanding of behavior under stress and residual performance possibilities after use are two of the features investigated using nondestructive testing. The use of ultrasonic, radiographic and holographic techniques in nondestructive testing is described. The role of aerospatiale in furthering the evolution of nondestructive testing techniques is discussed.

16/7/26 (Item 2 from file: 6)

1454891 NTIS Accession Number: PB90-865288/XAB

Nondestructive Testing of Composite Materials. April 1989-April 1990 (A Bibliography from the NTIS Database)

(Rept. for Apr 89-Apr 90)

National Technical Information Service, Springfield, VA.

Corp. Source Codes: 055665000

Apr 90 40p

Languages: English Document Type: Bibliography

Journal Announcement: GRAI9012

Supersedes PB89-858005. See also PB90-865270.

NTIS Prices: PC N01/MF N01

Country of Publication: United States

This bibliography contains citations concerning the nondestructive techniques for testing or examining a wide variety of composite materials. Topics discuss the detection of flaws or defects which affect the mechanical properties and behavior of composite materials. (This updated bibliography contains 52 citations, all of which are new entries to the previous edition.)

16/7/27 (Item 3 from file: 6)

1454890 NTIS Accession Number: PB90-865270/XAB

Nondestructive Testing of Composite Materials. January 1970-March 1989 (A Bibliography from the NTIS Database)

(Rept. for Jan 70-Mar 89)

National Technical Information Service, Springfield, VA.

Corp. Source Codes: 055665000

Apr 90 216p

Languages: English Document Type: Bibliography

Journal Announcement: GRAI9012

See also PB90-865288.

NTIS Prices: PC N01/MF N01

Country of Publication: United States

This bibliography contains citations concerning the nondestructive techniques for testing or examining a wide variety of composite materials. Topics discuss the detection of flaws or defects which affect the mechanical properties and behavior of composite materials. (This updated bibliography contains 357 citations, none of which are new entries to the previous edition.)

16/7/28 (Item 4 from file: 6)

1407698 NTIS Accession Number: N89-23632/7/XAB

Nouveaux Defis pour les Contrôles Non Destructifs des Matériaux Composites (Challenges of Nondestructive Testing of Composite Materials) Lefloch, C.

Aerospatiale, Saint-Medard-en-Jalles (France). Etablissement d'Aquitaine.

Corp. Source Codes: 090291001; AG943856

Sponsor: National Aeronautics and Space Administration, Washington, DC.

Report No.: REPT-882-430-107; ETN-89-94488

1988 12p

Languages: French

Journal Announcement: GRAI8920; STAR2717

Text in French.

NTIS Prices: PC A03/MF A01

Country of Publication: France

The quality control of composite materials is discussed, pointing out the most popular procedures in actual industrial practice including intermediate process controls; nondestructive control, and acoustic emission to study damaging; macroscopic evaluation tests (fiber rate, porosity rate, morphology); and defect characterization (delamination, impact, adhesion). The development of computer aided control and entirely automatic tests is examined.

16/7/29 (Item 5 from file: 6)

1407696 NTIS Accession Number: N89-23630/1/XAB

C.N.D. Des Matériaux Composites: Choix de la Méthode en Fonction du Besoin (Composite Materials Nondestructive Tests: Choice of Methods Depending on Requirements)

Barbier, P.

Aerospatiale, Saint-Medard-en-Jalles (France). Etablissement d'Aquitaine.

Corp. Source Codes: 090291001; AG943856

Sponsor: National Aeronautics and Space Administration, Washington, DC.

Report No.: REPT-882-430-105; ETN-89-94486

1988 11p

Languages: French

Journal Announcement: GRAI8920; STAR2717

Text in French.

NTIS Prices: PC A03/MF A01

Country of Publication: France

Nondestructive tests of high performance composite materials used in the aerospace industry such as carbon epoxy composites are discussed. Thermography, holography, and tomography are studied. It is shown that the optimum choice is very much dependent on the geometry and use of each specimen. It is indicated that the validity of the tests is the main problem to examine.

16/7/30 (Item 6 from file: 6)

1377786 NTIS Accession Number: PB89-858005/XAB

Nondestructive Testing of Composite Materials. January 1970-March 1989

(Citations from the NTIS Database)

(Rept. for Jan 70-Mar 89)

National Technical Information Service, Springfield, VA.

Corp. Source Codes: 055665000

Mar 89 216p

Languages: English Document Type: Bibliography

Journal Announcement: GRAI8910

Supersedes PB88-861281.

NTIS Prices: PC N01/MF N01

Country of Publication: United States

This bibliography contains citations concerning the nondestructive techniques for testing or examining a wide variety of composite materials. Topics discuss the detection of flaws or defects which affect the mechanical properties and behavior of composite materials. (This updated bibliography contains 357 citations, 33 of which are new entries to the previous edition.)

16/7/31 (Item 7 from file: 6)

1347132 NTIS Accession Number: N88-27250/5/XAB

Bilan d'Utilisation de la Radioscopie a Rayons X Appliquee au C.N.D. Des Materiaux Composites (Balance of X-ray Radioscopy Application to Nondestructive Tests of Composite Materials)

Loubet, D.

Societe Nationale Industrielle Aerospatiale, Saint-Medard-en-Jalles (France).

Corp. Source Codes: 072439000; SQ454255

Sponsor: National Aeronautics and Space Administration, Washington, DC.

Report No.: SNIAS-881-430-110; ETN-88-92858

1988 10p

Languages: French

Journal Announcement: GRAI8824; STAR2621

Text in French.

NTIS Prices: PC A02/MF A01

Country of Publication: France

The results obtained using X ray radioscopy nondestructive control equipment are discussed. Examples referring to composite materials are described. The limitations are discussed. The resolution and the noise problems limit the performance in delamination control, although the

application of digital techniques improves results. Remote video radioscopy is very useful for the nondestructive control of filament wound and woven composites, since the real time control of man-operation interactions is of great importance for this kind of product.

16/7/32 (Item 8 from file: 6)

1336483 NTIS Accession Number: PB88-867304/XAB

Nondestructive Testing of Composite Materials. January 1972-July 1988
(Citations from the International Aerospace Abstracts Database)

(Rept. for Jan 72-Jul 88)

National Technical Information Service, Springfield, VA.

Corp. Source Codes: 055665000

Aug 88 198p

Languages: English Document Type: Bibliography

Journal Announcement: GRAI8820

Supersedes PB87-865523. Prepared in cooperation with National Aeronautics and Space Administration, Washington, DC.

U.S. sales only.

NTIS Prices: PC N01/MF N01

Country of Publication: United States

This bibliography contains citations concerning the nondestructive techniques for testing or examining a wide variety of composite materials. Topics discuss the detection of flaws or defects which affect the mechanical properties and behavior of composite materials. (This updated bibliography contains 421 citations, 157 of which are new entries to the previous edition.)

16/7/33 (Item 9 from file: 6)

1328066 NTIS Accession Number: NTN88-0215/XAB

Ultrasonic Nondestructive Testing of Composites and Multi-Layer Materials
(NTIS Tech Note)

Department of the Air Force, Washington, DC.

Corp. Source Codes: 000260000

Mar 88 1p

Languages: English

Journal Announcement: GRAI8817

FOR ADDITIONAL INFORMATION: Detailed information about the technology described may be obtained by ordering the NTIS report NTIS order number AD-A1821990/ NAC, price code A06. To discuss the effort further, contact Thomas J. Moran, The University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0001; (513)255-5561.

NTIS Prices: See availability statement

Country of Publication: United States

This citation summarizes a one-page announcement of technology available for utilization. Emphasis on improved performance of Air Force systems has resulted in increased use of advanced, composite materials and structures. Composite materials and multi-layer structures provide increased strength, stiffness and reduced weight over conventional metallic structure. However, ensuring the structural integrity of these materials and structures is far more difficult than for materials. The complex microstructure and anisotropic behavior of composites makes detecting and characterizing defects or attempting quantitative NDE particularly difficult. Research carried out the development of new methods of ultrasonic nondestructive evaluation (NDE). A state-of-the-art, automated ultrasonic scanning system

was developed to provide the capability for improved data acquisition. Ultrasonic backscatter imaging and imaging using leaky surface waves are applied to locating defects in advanced fiber-reinforced composite materials.

16/7/34 (Item 10 from file: 6)
1315152 NTIS Accession Number: PB88-861281/XAB
Nondestructive Testing of Composite Materials. January 1970-March 1988
(Citations from the NTIS Database)
(Rept. for Jan 70-Mar 88)
National Technical Information Service, Springfield, VA.
Corp. Source Codes: 055665000
Apr 88 169p
Languages: English Document Type: Bibliography
Journal Announcement: GRAI8812
Supersedes PB87-855565.
NTIS Prices: PC N01/MF N01
Country of Publication: United States
This bibliography contains citations concerning the nondestructive techniques for testing or examining a wide variety of composite materials. Topics discuss the detection of flaws or defects which affect the mechanical properties and behavior of composite materials. (This updated bibliography contains 324 citations, 53 of which are new entries to the previous edition.)

16/7/35 (Item 11 from file: 6)
1302217 NTIS Accession Number: N88-13400/2/XAB
Philosophie et Pratique des Cnd des Structures en Matériaux Composites a l'Aérospatiale Aquitaine (Philosophy and Practice of Nondestructive Tests of Composite Material Structures at Aérospatiale Aquitaine)
Lefloch, C.
Société Nationale Industrielle Aérospatiale, Saint-Médard-Jalles (France).
Corp. Source Codes: 072439000; SQ454255
Sponsor: National Aeronautics and Space Administration, Washington, DC.
Report No.: SNIAS-872-430-105; ETN-88-91216
1987 6p
Languages: French
Journal Announcement: GRAI8808; STAR2605
Text in French. Presented at the Journées sur Contrôle Non Destructif et Matériaux Composites, Paris, France, April 7, 1987.
NTIS Prices: PC A02/MF A01
Country of Publication: France
The nondestructive test implementing the quality control procedures of an aircraft manufacturer are described. These are mainly X-ray or ultrasonic procedures. Procedures being studied or in development are discussed, including photothermic analysis, photoacoustics, acoustic microscopy, diffused X-rays, neutronography, and nuclear magnetic resonance.

16/7/36 (Item 12 from file: 6)
1268689 NTIS Accession Number: PB87-865523/XAB
Nondestructive Testing of Composite Materials. January 1972-August 1987
(Citations from the International Aerospace Abstracts Database)
(Rept. for Jan 72-Aug 87)

National Technical Information Service, Springfield, VA.

Corp. Source Codes: 055665000

Aug 87 125p

Languages: English Document Type: Bibliography

Journal Announcement: GRAI8720

Supersedes PB86-872710. Prepared in cooperation with National Aeronautics and Space Administration, Washington, DC.

U.S. sales only.

NTIS Prices: PC N01/MF N01

Country of Publication: United States

This bibliography contains citations concerning the nondestructive techniques for testing or examining a wide variety of composite materials. Topics discuss the detection of flaws or defects which affect the mechanical properties and behavior of composite materials. (This updated bibliography contains 264 citations, 34 of which are new entries to the previous edition.)

16/7/37 (Item 13 from file: 6)

1234992 NTIS Accession Number: PB87-855565/XAB

Nondestructive Testing of Composite Materials. 1970-February 1987

(Citations from the NTIS Database)

(Rept. for 1970-Feb 87)

National Technical Information Service, Springfield, VA.

Corp. Source Codes: 055665000

Feb 87 140p

Languages: English Document Type: Bibliography

Journal Announcement: GRAI8708

Supersedes PB86-858289.

NTIS Prices: PC N01/MF N01

Country of Publication: United States

This bibliography contains citations concerning the nondestructive techniques for testing or examining a wide variety of composite materials. Topics discuss the detection of flaws or defects which affect the mechanical properties and behavior of composite materials. (This updated bibliography contains 271 citations, 33 of which are new entries to the previous edition.)

16/7/38 (Item 1 from file: 4)

03949710 INSPEC Abstract Number: A91111884

Title: Acousto-ultrasonic technique for nondestructive evaluation of composite materials. A review. 1

Author(s): Doyum, A.B.

Journal: Materialpruefung vol.33, no.6 p.175-7

Publication Date: June 1991 Country of Publication: West Germany

CODEN: MTPRAJ ISSN: 0025-5300

Language: English Document Type: Journal Paper (JP)

Treatment: Theoretical (T)

Abstract: In a two part study, a review based on the emerging technique of determining the acousto-ultrasonic stress wave factor is presented. In Part 1, the principles and applications of the method are described. Some of the key publications on acousto-ultrasonic which use the technique for material strength correlation and damage assessment in fibre reinforced composites are outlined. In Part 2, further applications of the method along with its advantages and limitations, and possible means of

improvement will be discussed. (11 Refs)

16/7/39 (Item 2 from file: 4)

03897749 INSPEC Abstract Number: A91076439

Title: Nondestructive evaluation of composite materials using acoustic microscopy

Author(s): Nongaillard, B.; Rouvaen, J.M.; Imouloudene, N.E.

Author Affiliation: Lab. d'Opto-Acousto-Electron., Valenciennes Univ., France

Conference Title: Acoustical Imaging. Vol.17 p.111-19

Editor(s): Shimizu, H.; Chubachi, N.; Kushibiki, J

Publisher: Plenum, New York, NY, USA

Publication Date: 1989 Country of Publication: USA xiii+791 pp.

ISBN: 0 306 43150 5

Conference Date: 31 May-2 June 1988 Conference Location: Sendai, Japan

Language: English Document Type: Conference Paper (PA)

Treatment: Experimental (X)

Abstract: The authors explain the mechanism responsible for the contrast in the images of composite samples obtained using acoustic microscopy. (10 Refs)

16/7/40 (Item 3 from file: 4)

03645012 INSPEC Abstract Number: A90084469

Title: Nondestructive evaluation of composite materials using ultrasonic spectroscopy

Author(s): Ourak, M.; Nongaillard, B.; Rouvaen, J.M.; Imouloudene, N.

Author Affiliation: Lab. d'Opt.-Acoust.-Electron., ENSIMEV, Valenciennes Univ., France

Journal: Colloque de Physique no.C-2, pt.2 p.1261-4

Publication Date: Feb. 1990 Country of Publication: France

ISSN: 0449-1947

Conference Title: First French Conference on Acoustics

Conference Date: 10-13 April 1990 Conference Location: Lyon, France

Language: English Document Type: Conference Paper (PA); Journal Paper (JP)

Treatment: Practical (P)

Abstract: The nondestructive evaluation of the carbon epoxy composite materials (often used in aeronautics) is a difficult matter. The classical control methods prove unsatisfactory for the detection of distributed defects (like delaminations and porosities), which affect severely the mechanical properties of composite parts. Ultrasonic echography (A scan mode) allows for the detection of some kinds of delaminations, but the interpretation of the echographic signal remains difficult in the case of porosities and owing to the heterogeneous nature of composites. The usefulness of a spectral analysis (ultrasonic spectroscopy) is demonstrated: the occurrence of selective absorption frequencies, closely bound to the material internal structure, is evidenced. Several examples of spectral analysis of the transmitted or reflected ultrasound are presented for reasonably defect-free and porous materials. (6 Refs)

16/7/41 (Item 1 from file: 293)

095515 EMA Number: 9112-B2-D-0690

New Nondestructive Testing Method for Advanced Composite Materials Using X-Ray Backscattering.

Roye, W

Phillips

Advanced Materials: Cost Effectiveness, Quality Control, Health and Environment, Maastricht, The Netherlands, 28-30 May 1991

p. 265-271

Publ: Elsevier Science Publishers BV, Sara Burgerhartstraat 25, PO Box 211, 1000 AE Amsterdam, The Netherlands, 1991

Journal Announcement: 9112

Document Type: BOOK

Language: ENGLISH

A number of modern materials like fibre composites or sandwich constructions offer, due to their versatility, a vast field of future applications. However, within many cases the well known nondestructive techniques fail. For these advanced materials the new nondestructive method--ComScan--is presented, which fulfils within wide ranges the requirements for the inspection of fibre reinforced and sandwich composites. Graphs, Photomicrographs.--AA

16/7/42 (Item 2 from file: 293)

090486 EMA Number: 9109-B2-D-0483

Ultrasonic Nondestructive Evaluation Technology for Adhesive Bond and Composite Material Inspection.

Rose, J L

Drexel University

Adhesive Bonding, p. 425-448

Publ: Plenum Press, 233 Spring St., New York, New York 10013, USA, 1991

Journal Announcement: 9109

Document Type: ARTICLE

Language: ENGLISH

Ultrasonic wave generation, wave velocity, dispersion, reflection factor, wave refraction, attenuation, and thickness and defect location measurement in adhesively-bonded metal and polymer matrix structures are described. The utility of probability-density-function analysis for inspectability, damage analysis, and F-map generation is shown. Feasibility studies on Al-to-Al bond inspection are discussed and the results of color graphics display samples are presented. Signal processing and pattern recognition for high-frequency analysis are addressed. Recent work in oblique incidence-wave generation for reflectivity, shear wave, and plate-wave generation is summarized. Graphs. 45 ref.--D.M.Y.

16/7/43 (Item 3 from file: 293)

083823 EMA Number: 9105-B2-D-0253

Nondestructive Evaluation of Ceramic Matrix Composites.

Kunerth, D C ; Lott, L A ; Walter, J B

Idaho National Engineering Laboratory

14th Annual Conference on Composites and Advanced Ceramic Materials. II, Cocoa Beach, Florida, USA, 14-17 Jan. 1990

Ceramic Engineering and Science Proceedings, 11, (9-10), p. 1685-1688

ISSN: 0196-6219

Publication Date: Sept.-Oct. 1990

1990

Journal Announcement: 9105

Document Type: ARTICLE

Language: ENGLISH

Reasonable correlations were observed between the measured ultrasonic properties of velocity, attenuations, and damping, and the material properties of porosity and SiC fiber/SiC matrix interface bond strength. Thus ultrasonic properties can be used to map porosity distributions, as well as detect variations in the fiber-matrix bonds. However, since ultrasonics are sensitive to both material properties, a complementary technique such as X-ray radiography must be used to distinguish which material property of variation is being measured. Graphs. 7 ref.--AA

16/7/44 (Item 4 from file: 293)

077786 EMA Number: 9101-B2-D-0056

Image Processing of Composite Materials Using Ultrasonic Nondestructive Evaluation Data.

Blake Jr, R A

Alcoa Technical Center

Non-Destructive Testing of Fibre-Reinforced Plastics Composites. Vol. 2, p. 161-200

Publ: Elsevier Science Publishers, Crown House, Linton Road, Barking, Essex IG11 8JU, UK, 1990

Journal Announcement: 9101

Document Type: ARTICLE

Language: ENGLISH

The methods discussed deal with ultrasonic results from composite material interrogations. X-ray, thermographic, eddy current, photographic and a variety of other fields can all benefit from the use of quantitative image processing. The ability to reliably inspect composite materials and interpret the inspection results has been dramatically facilitated and enhanced through the use of image processing techniques. It is expected that the incorporation of signal pattern recognition techniques will allow for the classification of material anomalies by type as well as by location and will thus aid in structural integrity evaluations as well as in lifetime predictions. Graphs. 64 ref.--AA

16/7/45 (Item 5 from file: 293)

074360 EMA Number: 9011-B2-D-0734

Quantitative Characterization of Impact Damage in Composite Materials--a Comparison Between Computerized Vibrothermography and X-Ray Tomography.

Potet, P ; Lesbre, F ; Bathias, C

Nondestructive Testing and Evaluation for Manufacturing and Construction, Urbana-Champaign, Illinois, USA, 9-12 Aug. 1988

p. 95-105

Publ: Hemisphere Publishing Corporation, 79 Madison Ave., New York, New York 10016-7892, USA, 1990

Journal Announcement: 9011

Document Type: BOOK

Language: ENGLISH

A new technique, vibro-thermography, was developed and proposed for application to composites. It utilizes high frequency, low-amplitude mechanical vibrations to induce localized heating in a material. The frequency of excitation is varied in such a way that local flawed regions are set into local resonance, and serve as generators of heat. Some experimental results obtained by vibrothermography are compared with those obtained by X-ray tomography in the characterization of impact damage in composite materials. The X-ray tomography data will serve as reference to

evaluate the possibilities offered by vibrothermography. The material tested was a graphite/epoxy laminate. 5 ref.--AA

16/7/46 (Item 6 from file: 293)

072576 EMA Number: 9010-B2-D-0667

Characterizing Porosity of Composite Materials Through Digital Ultrasonic Waveform Processing.

Weber, S ; Blake Jr, R A ; Teti Jr, R ; Boncelet, C

Visual Edge Software, Alcoa Technical Center, Universita di Napoli

Review of Progress in Quantitative Nondestructive Evaluation. Vol. 8B, La Jolla, California, USA, 1-5 Aug. 1988

p. 1575-1580

Publ: Plenum Press, 233 Spring Street, New York, New York 10013, USA, 1989

Journal Announcement: 9010

Document Type: BOOK

Language: ENGLISH

A method is presented to detect and quantify the porosity value content of composite materials, part of a development effort to establish an integrated ultrasonic evaluation system. The overall research effort aims to automate the NDE process and predict mechanical and structural properties of composite materials using NDE techniques. The ultrasonic NDE technique used is based on digitized waveforms obtained from pulse-echo scans. For the fast integration of new algorithms into the system, a software framework was created with compatibility between the signal and image processing modules. The porosity volume content of the test specimens is related to statistical properties of the ultrasonic data rather than to the ultrasonic attenuation with respect to frequency. Graphs, Photomicrographs. 5 ref.--AA

16/7/47 (Item 7 from file: 293)

072565 EMA Number: 9010-B2-D-0656

Damage Assessment for Composite Materials Based on Structurally Imbedded Optical Fibers and Image Enhanced Backlighting.

Measures, R M ; Glossop, N D W ; Lymer, J

University of Toronto

Review of Progress in Quantitative Nondestructive Evaluation. Vol. 8B, La Jolla, California, USA, 1-5 Aug. 1988

p. 1457-1465

Publ: Plenum Press, 233 Spring Street, New York, New York 10013, USA, 1989

Journal Announcement: 9010

Document Type: BOOK

Language: ENGLISH

In the assessment system described, the distribution of light directed via an optical-fibre (OF) bundle to a grid of specially treated OFs imbedded within a composite panel represents the reference transmission state. Impact damage to the panel, as indicated by breakage of the OFs, is then compared with indications from visual inspection, image-enhancing backlighting (IEB), and ultrasonic C-scans. Results with Kevlar-fibre/epoxy panels, the translucence of which facilitated precise location of the fracture along each OF and direct observation of the delamination region, quantified the threshold impact energy for fracture and revealed three possible fracture mechanisms. The validity and benefits of the technique

are discussed with particular reference to the IEB and the special OF treatment permitting the detection of barely visible damage. Graphs, Photomicrographs. 6 ref.--J.R.

16/7/48 (Item 8 from file: 293)
070890 EMA Number: 9009-B2-D-0574
Non-Destructive Evaluation of Composite Material Using Ultrasound.
(Retroactive Coverage).
Dayal, V ; Kinra, V K
Texas A&M University
16th Symposium on Nondestructive Evaluation, San Antonio, Texas, USA,
21-23 Apr. 1987
p. 125-131
Publ: Southwest Research Institute, NTIAC, P.O. Drawer 28510, San
Antonio, Texas 78284, USA, 1987
Journal Announcement: 9009
Document Type: BOOK
Language: ENGLISH

The stiffness of fiber-reinforced composites (e.g. AS4/3502) is reduced and damping is increased because of the development of microdamage due to mechanical, thermal or humidity loading. The measurement of the reduction in stiffness and increase in ultrasonic attenuation of fiber-reinforced composites due to transverse cracks both in out-of-plane and in-plane directions are reported. Graphs. 4 ref.--AA

16/7/49 (Item 9 from file: 293)
070889 EMA Number: 9009-B2-D-0573
A Comparative Study of Ultrasonic Inspection Techniques for Composite Materials. (Retroactive Coverage).
Bouvier, C G
Martin Marietta Michoud Aerospace
16th Symposium on Nondestructive Evaluation, San Antonio, Texas, USA,
21-23 Apr. 1987
p. 108-118
Publ: Southwest Research Institute, NTIAC, P.O. Drawer 28510, San
Antonio, Texas 78284, USA, 1987
Journal Announcement: 9009
Document Type: BOOK
Language: ENGLISH

The purpose was to compare detection capabilities of two traditional ultrasonic inspection methods, pulse-echo and through-transmission, for the detection of flaws in composite materials. In this evaluation, variations to the traditional procedures were investigated to determine their potential for enhancement in flaw detection capability. These variations include back-surface amplitude monitoring for the pulse-echo method, and use of a focused receiver with a flat beam transmitter for the through-transmission method. In addition, a color-enhanced C-scan system was utilized to improve the flaw interpretation capability. The composite test panels used in this study were fabricated from graphite--epoxy and quartz--epoxy materials ranging in thickness from approx 0.10-0.50 in. (6-32 plies). These contained various types of flaws occurring at different locations (near-, sub-, and back-surface) in the panel. Results are presented to elucidate the advantages and disadvantages of the two modified methodologies. Graphs, Photomicrographs.--AA

16/7/50 (Item 10 from file: 293)

067820 EMA Number: 9007-C1-D-1635

Nondestructive Evaluation of Composite Material Using Ultrasound.

Kinra, V K ; Dayal, V

Texas A&M University

Acousto-Ultrasonics: Theory and Application, Blacksburg, Virginia, USA,

12-15 July 1987

p. 143-150

Publ: Plenum Press, 233 Spring St., New York, New York 10013, USA, 1988

Journal Announcement: 9007

Document Type: BOOK

Language: ENGLISH

Transverse cracks as a mode of damage are investigated. The changes in the wavespeed and attenuation are measured as a function of damage. Some results are presented from the tests of cross-ply and angle-ply graphite/epoxy laminates. The reduction in the in-plane stiffness and an increase in the attenuation is observed as the number of transverse cracks increase. Graphs. 4 ref.--AA

16/7/51 (Item 11 from file: 293)

063087 EMA Number: 9004-B2-D-0228

NDE of Thick GFRP Composites Through Ultrasonic Waveform Detection.

Teti, R ; Caprino, G

University of Naples

Developments in the Science and Technology of Composite Materials. ECCM 3

, Bordeaux, France, 20-23 Mar. 1989

p. 793-800

Publ: Elsevier Science Publishers, Crown House, Linton Road, Barking, Essex, IG11 8JU, UK, 1989

Journal Announcement: 9004

Document Type: BOOK

Language: ENGLISH

Ultrasonic non-destructive evaluation of thick glass fiber reinforced plastic composites was carried out using a complete waveform digital acquisition and analysis technique. It is shown that this method yields detailed information on the entire material volume, providing for the accurate localization of defects. The availability of complete waveform data files makes it possible to generate images acting as interfaces between user and ultrasonic database and to statistically process the data to obtain information on the material global properties. Material quality, determined through this technique, was found to be in good agreement with the results of macroscopic examinations. 9 ref.--AA

16/7/52 (Item 12 from file: 293)

059757 EMA Number: 9002-B2-D-0064

Radiographic NDT of Composite Materials.

Becker, G

Du Pont de Nemours

NDT Today, (1), p. 10-11

Publication Date: 1988

1988

Journal Announcement: 9002

Document Type: ARTICLE

Language: ENGLISH

In the aerospace industry, there is an increased demand for composite materials. Kevlar aramid fiber and carbon--epoxy material are the most common for lower temperature applications. At high temperatures, graphite--polyimides are used up to 600 deg F (316 deg C), metal matrix up to 1300 deg F (704 deg C) and C--C ceramics for temperatures up to 2500 deg F (1371 deg C). When considering radiography of these materials, the atomic numbers of the matrix materials become the driver for sensitivity levels. The radiography of lower atomic number materials is done at extremely low kilovoltages, to achieve the highest contrast. Metal matrix composites require a higher kilovoltage for X-radiography. Guidelines are given for the choice of exposure times, penetrameters (image quality indicators), film holders and the viewing of radiographs. --D.O.N.

16/7/53 (Item 13 from file: 293)

056727 EMA Number: 8912-B2-D-0713

Holographic Nondestructive Testing of Composite Materials for Aeronautical Structures.

Delvo, P ; Ferraro, P ; Rizzi, M L ; Sabatino, C

Aeritalia

1989 SEM Spring Conference on Experimental Mechanics, Cambridge, Massachusetts, USA, 29 May-1 June 1989

p. 714-719

Publ: Society for Experimental Mechanics, Inc., 7 School St., Bethel, Connecticut 06801, USA, 1989

Journal Announcement: 8912

Document Type: BOOK

Language: ENGLISH

Holographic interferometry can be successfully used for detection and interpretation of defects such as delaminations, debonds and non-adherence in composite materials. The results obtained by applying this technique as a NDT tool to aircraft structures made of composite materials (e.g. carbon fiber reinforced epoxy resin) are illustrated. Particular attention is devoted to the various kinds of stresses which must be induced into the test pieces to evaluate the defects with complete reliability. 4 ref.--AA

16/7/54 (Item 14 from file: 293)

056721 EMA Number: 8912-B2-D-0707

NDT of Some Advanced Composite Materials.

Bridge, B ; Round, R ; Izzard, C J ; Oaten, S R

Brunel University

Anglo-Finnish Joint Symposium on Advances in Nondestructive Testing, Espoo, Finland, 9-11 May 1988

Report No.: VTT 93 p. 38-74

Publ: Technical Research Centre of Finland, Vuorimiehentie 5, SF-02150 Espoo, Finland, 1988

Journal Announcement: 8912

Document Type: REPORT

Language: ENGLISH

Typical results of a number of complementary NDT techniques, for the evaluation of three very different advanced composites, are described. Firstly, polyethylene filled with particulate hydroxyapatite, a synthetic bone material, currently undergoing trials for hip and knee replacement surgery is considered. The composition dependence of the ultrasonically

determined elastic moduli, and the composition and frequency dependence of the compressional wave attenuation, are described. The second material is a chemically bonded ceramic composite consisting of alumina and magnesia in reaction with aluminium orthophosphate in a solution of orthophosphoric acid, and reinforced with glass or carbon fibres. By virtue of its unusual thermal properties this material has been envisaged for, among other things, stealth technology applications, e.g. minimisation of infrared signatures when used in aero engine casings. Presently, the prototype material suffers from serious void defects. The frequency dependence of compressional wave attenuation has been studied in the 100 Hz-10 MHz range using combined narrowband and broadband spectrum analysis techniques. The third composite, polypropylene filled with short steel fibres, has applications in defence for microwave shielding and, in particular, for stealth technology, i.e. minimisation of radar signatures. An important performance indicator for this material is the fibre distribution. Ultrasonic C-scan images and eddy current contour maps of the fibre content are compared with radiological images. Graphs, spectra. 21 ref.--AA

16/7/55 (Item 15 from file: 293)
055277 EMA Number: 8911-B2-D-0618
Characterization of Carbon-Epoxy Composites Using Physicochemical, Mechanical, and Nondestructive Test Methods.
Cole, K C ; Noel, D ; Cielo, P
National Research Council of Canada, Canadaair
International Conference on Analytical and Testing Methodologies for Design With Advanced Materials. ATMAM 87, Montreal, Quebec, Canada, 26-28 Aug. 1987
Report No.: 4.16 p. Pp 10
Publ: Concordia University, Montreal, Quebec, Canada, 1987
Journal Announcement: 8911
Document Type: REPORT
Language: ENGLISH
Results obtained using a number of different techniques for characterizing composite materials are reported and the relationships among them are studied. The results are based on a study of the room-temperature aging of the C-epoxy system Narmco Rigidite 5208/WC3000. Samples of prepreg were exposed at 22 deg C and 50% relative humidity for up to 66 days. Significant changes in resin chemistry due to polymerization were observed using Fourier transform infrared spectroscopy, liquid chromatography, and thermal analysis. Certain physical properties, notably the gel time, were also affected. Test panels made from aged prepreg were examined by mechanical testing, ultrasonic scanning, and optothermal inspection. Significant variations were observed but they did not correlate with the extent of prepreg aging. Instead, they appear to be due to differences in homogeneity arising from other factors in the panel fabrication procedure. A good correlation was observed between the tensile modulus and the thermal diffusivity, which indicates that the latter may be valuable as a nondestructive test method for C-epoxy composites. Graphs. 3 ref.--AA

16/7/56 (Item 16 from file: 293)
052548 EMA Number: 8909-B2-D-0520
Processing of Thermal Images for the Detection and Enhancement of Subsurface Flaws in Composite Materials.

Maldague, X ; Krapez, J C ; Cielo, P ; Poussart, D
National Research Council of Canada, Universite Laval
Signal Processing and Pattern Recognition in Nondestructive Evaluation of
Materials, Lac Beauport, Quebec, Canada, 19-22 Aug. 1987
p. 257-285

Publ: Springer-Verlag, Heidelberger Platz 3, Postfach D-1000 Berlin 33,
FRG, 1988

Journal Announcement: 8909

Document Type: BOOK

Language: ENGLISH

Subsurface imaging using thermal wave generated either by line heating with lateral displacement of the part to be inspected or full-field heating with no displacement is an attractive approach for the NDE of composite materials. Proper detection of flaws, such as delaminations or unbonds require dedicated thermographic image processing. Detection and enhancement of unbonds in Al to foam laminates is discussed. Also quantitative characterization of flaws in graphite--epoxy laminates using specially developed image processing and modelling is presented. Emphasis is given to either time-domain or space-domain image processing methods for precise and reliable defect visualization. 30 ref.--AA

16/7/57 (Item 17 from file: 293)

051197 EMA Number: 8908-B2-D-0454

Nondestructive Evaluation of Composite Laminates by Leaky Lamb Waves Using a Bubbler Device.

Bar-Cohen, Y ; Chimenti, D E

McDonnell Douglas, Air Force Wright Aeronautical Laboratories

Nondestructive Characterization of Materials II., Montreal, Canada,

21-23 July 1986

p. 89-93

Publ: Plenum Publishing Corporation, 233 Spring Street, New York, NY
10013, USA, 1987

Journal Announcement: 8908

Document Type: BOOK

Language: ENGLISH

The application of Leaky Lamb waves (LLW) to nondestructive testing in field conditions was studied using a bubbler device. To reduce the sensitivity of LLW modes to surface curvature, the dispersion curve of LLW in graphite/epoxy laminates was used in the design of the bubbler. The results are described and discussed. 2 ref.--AA

16/7/58 (Item 18 from file: 293)

051193 EMA Number: 8908-B2-D-0450

Process Controls and Nondestructive Evaluation of Structural Composites.

Hadcock, R N ; Donohue, P J ; Chance, R F

Grumman Aircraft Systems

Nondestructive Characterization of Materials II., Montreal, Canada,

21-23 July 1986

p. 1-18

Publ: Plenum Publishing Corporation, 233 Spring Street, New York, NY
10013, USA, 1987

Journal Announcement: 8908

Document Type: BOOK

Language: ENGLISH

Current process controls and nondestructive evaluation techniques are adequate for assuring the quality of most of today's structural and composite parts. However, in many cases these procedures are very labor- and skill-intensive, resulting in high quality control costs. Quality control procedures must be integrated and automated wherever possible to improve quality and minimize the costs. This will be especially important as most complex structures are built utilizing automated manufacturing techniques. 3 ref.--AA

16/7/59 (Item 19 from file: 293)

047073 EMA Number: 8905-B2-D-0260

NDT of Composite Structures Used in Space Applications.

Koshy, T C

Vikram Sarabhai Space Centre

Composite Materials and Structures, Madras, India, 6-9 Jan. 1988

p. 417-423

Publ: Tata McGraw-Hill Publishing Company Limited, 4/12 Asaf Ali Road, New Delhi 110 002, India, 1988

Journal Announcement: 8905

Document Type: BOOK

Language: ENGLISH

NDT techniques for composite structures have been reviewed, but none can be considered as universal for composites. A number of parameters such as minimum detectable flaw, shape and thickness of the part, type and direction of flaw, instrument availability and ease of implementing operation have to be satisfied to provide a suitable NDT technique. It should also be borne in mind that several NDT techniques used in conjunction can only bring out the most successful evaluation of a composite structure. 5 ref.--AA

16/7/60 (Item 20 from file: 293)

041418 EMA Number: 8901-B2-C-0022

Improving the Reliability of High-Performance Ceramics Using Nondestructive Evaluation.

Cotter, D J ; Koenigsberg, W D ; Pasto, A E ; Bowen, L J

GTE Laboratories

12th Annual Conference on Composites and Advanced Ceramic Materials. II, Cocoa Beach, Florida, USA, 17-22 Jan. 1988

Ceram. Eng. Sci. Proc., 9, (7-8), p. 1503-1516 ISSN: 0196-6219

Publication Date: July-Aug. 1988

1988

Journal Announcement: 8901

Document Type: ARTICLE

Language: ENGLISH

Results are presented from a program to improve the reliability of advanced silicon nitride ceramics through the use of nondestructive evaluation. A large quantity of silicon nitride test bars was inspected by microfocus radiography. In total, 76 bars were rejected because they contained major naturally-occurring voids. A digital image processing system was used to obtain data on size, shape, and location of the voids. Failure stress was predicted based on a fracture mechanics model. For comparison, actual failure stress was measured for the bars and then related to the stress at the flaw location by an elemental analysis. Fractography was also performed on the broken bars. The Weibull modulus of

the NDE rejected samples was 3.9, compared with 13.0 for the NDE accepted samples. 27 ref.--AA

16/7/61 (Item 21 from file: 293)

041415 EMA Number: 8901-B2-C-0019

Deblurring of Conventional Tomography Images With Applications to the NDE of Advanced Ceramics.

Hentea, T ; Ellingson, W A ; Roberts, R A ; Kriz, R J

Purdue University, Argonne National Laboratory, University of Illinois

12th Annual Conference on Composites and Advanced Ceramic Materials. II,

Cocoa Beach, Florida, USA, 17-22 Jan. 1988

Ceram. Eng. Sci. Proc., 9, (7-8), p. 1471-1481 ISSN: 0196-6219

Publication Date: July-Aug. 1988

1988

Journal Announcement: 8901

Document Type: ARTICLE

Language: ENGLISH

Low-cost X-ray tomographic imaging methods may be useful for detecting defects in structural ceramics. Conventional film-based tomography systems, although potentially inexpensive, produce images that are affected by blurring caused by the structure of the object above and below the tomographic plane of interest. The blur can be removed by using digital image processing techniques. Described are three methods for deblurring images of ceramic specimens: inverse filtering, iterative approximation, and multiplane approximation. 10 ref.--AA

16/7/62 (Item 22 from file: 293)

033217 EMA Number: 8807-B2-D-0252

Nondestructive Evaluation of Residual Stress in Composites and Advanced Materials: a State-of-the-Art Review.

Matzkanin, G A

Southwest Research Institute

Residual Stresses in Science and Technology. Vol. 1,

Garmisch-Partenkirchen, FRG, 1986

p. 101-108

Publ: DGM Informationsgesellschaft mbH, Adenauerallee 21, D-6370 Oberursel 1, FRG, 1987

Journal Announcement: 8807

Document Type: BOOK

Language: ENGLISH

A qualitative summary of the current state-of-the-art for NDE of residual stress in advanced materials and composites, as determined from the literature search and review described, is shown. The results presented are based on the limited, qualitative evaluation of the available literature. While there are no NDE techniques currently available for general, practical application for residual stress measurement in advanced materials and composites, the techniques listed, appear from the literature, to be the most promising at the present time for development for practical application. These are for organic matrix composites: stress-wave analysis (acoustic emission and thermal-elastic) and embedded sensors (fiber optic and microdielectrics); for metal matrix composites and ceramics: X-ray diffraction and ultrasonics. 7 ref.--AA

16/7/63 (Item 23 from file: 293)

025102 EMA Number: 8712-B2-D-0543

Leaky Plate Waves for NDE of Composites.

Chimenti, D E ; Fiedler, C J

11th Annual Conference on Composites and Advanced Ceramic Materials,
Cocoa Beach, Florida, USA, 18-23 Jan. 1987

Ceram. Eng. Sci. Proc., 8, (7-8), p. 538-546 ISSN: 0196-6219

Publication Date: July-Aug. 1987
1987

Journal Announcement: 8712

Document Type: ARTICLE

Language: ENGLISH

Ultrasonic leaky plate wave propagation in silicon carbide (SiC) fiber reinforced glass composite laminates has been investigated using acoustic reflection methods. From ultrasonic measurements on a unidirectional composite plate, experimental velocity dispersion curves for plate wave modes have been constructed. A simple theoretical model has been fitted to the data. The model has been used to estimate some of the unknown constituent elastic constants. Nondestructive characterization techniques, exploiting leaky plate waves in a scanning configuration, are demonstrated. These scans permit the construction of detailed spatial maps of elastic behavior or occurrence of discontinuities in the composite. 16 ref.--AA

16/7/64 (Item 24 from file: 293)

025089 EMA Number: 8712-B2-C-0530

NDE and Fracture Studies of Hot-Pressed Si sub 3 N sub 4 .

Roberts, R A ; Singh, J P ; Vaitekunas, J J

11th Annual Conference on Composites and Advanced Ceramic Materials,
Cocoa Beach, Florida, USA, 18-23 Jan. 1987

Ceram. Eng. Sci. Proc., 8, (7-8), p. 493-501 ISSN: 0196-6219

Publication Date: July-Aug. 1987
1987

Journal Announcement: 8712

Document Type: ARTICLE

Language: ENGLISH

Recent correlations of nondestructive evaluation (NDE) and fractography results to establish the relative effectiveness of various NDE techniques in detecting and identifying failure-causing flaws in hot-pressed Si sub 3 N sub 4 are presented. Ultrasonic and low-kV X-ray data are compared with fractography results. 10 ref.--AA

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